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PREDICTED EFFECTS OF HYDROPOWER UPRATE ON TROUT HABITAT IN THE CUMBERLAND RIVER, DOWNSTREAM OF WOLF CREEK DAM, KENTUCKY

by

John M. Nestler, James A. Gore, L. Toni Curtis, James L. Martin

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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The US Army Engineer District, Nashville (ORN), regulates flows in the Cumberland River at Wolf Creek Dam to provide for hydropower generation and flood control. The ORN is considering uprating the Wolf Creek Dam powerhouse to meet future demands for power in the region by replacing existing turbines with new units having higher capacity. With the proposed new units, maximum hydropower discharge will increase with a concomitant decrease in duration of generation.

This report describes and quantifies the effects of hydropower uprating on downstream habitat of adult rainbow trout, juvenile brown trout, and adult brown trout using Instream Flow Incremental Methodology concepts. The relative downstream habitat impacts of hydropower uprate are assessed by contrasting existing and uprate release schedules under the following three hydrologic conditions: low flow (90-percent exceedance), average flow

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(50-percent exceedance), and high flow (10-percent exceedance). In general, predicted habitat availability for adult rainbow trout and adult brown trout decreases under uprate release schedules for low- and average-flow hydrologic conditions. Under high-flow conditions, habitat availability for the adult life stages increases. Habitat for juvenile brown trout is generally negligible under both existing and uprate release schedules, and consistent patterns were not observed.

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PREFACE

This study was conducted by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The work was funded by the US Army Engineer District, Nashville, under Intra-Army Order for Reimbursable Services No. 85-0070, dated 2 April 1985 and amended 26 June 1985 and 7 October 1986.

The report was prepared by Dr. John M. Nestler, Dr. James A. Gore, Ms. L. Toni Curtis, and Dr. James L. Martin, EL. Dr. Gore was employed by the WES under the terms of an Intergovernmental Personnel Act agreement with the University of Tulsa, Tulsa, OK. The report was prepared under the direct supervision of Mr. Mark S. Dortch, Chief, Water Quality Modeling Group (WQMG), EL, and under the general supervision of Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division, EL, and Dr. John Harrison, Chief, EL. Technical review was performed by Mr. Richard Coleman, Environmental Resources Division, EL, and Dr. Marc Zimmerman, WQMG. Mr. Kyle Bertrand, WQMG, prepared the graphics for the report. Ms. Jessica S. Ruff of the WES Information Technology Laboratory edited the report.

COL Dwayne G. Lee, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

PREDICTED EFFECTS OF HYDROPOWER UPRATE ON TROUT HABITAT IN THE CUMBERLAND RIVER DOWNSTREAM OF WOLF CREEK DAM, KENTUCKY

PART I: INTRODUCTION

Background

1. The US Army Engineer District, Nashville (ORN), regulates flows in the Cumberland River at Wolf Creek Dam, located at river mile (RM) 460.9, to provide for hydropower production and flood control. Located in southeastern Kentucky, Wolf Creek Dam is an integral part of a coordinated system for flood protection in the Cumberland and Ohio River valleys, significantly reducing flood stages at Nashville, TN, and contributing to flood damage reduction as far downstream as the lower Mississippi River. The dam is a combination earthfill and concrete structure 5,736 ft* long and 258 ft high, with a gated spillway. Six hydroelectric generating units with a total capacity of 270,000 kW were installed at Wolf Creek Dam and placed on-line for power production between 1951 and 1952. The estimated average annual energy output of the existing Wolf Creek power plant is about 800 million kWhr.

2. To aid in meeting future power demands, modification of the hydropower generation capabilities at Wolf Creek Dam is under consideration. These modifications include the addition of new units, refitting or uprating of existing units, and a change from baseload generation to peaking power generation. The project currently releases a daily averaged flow of 9,160 cfs, with a maximum release of 40,000 cfs. Revised operating plans under consideration would increase flows to a maximum of 60,000 cfs.

3. The Cumberland River downstream of Wolf Creek Dam currently supports a valuable "put-and-take" trout fishery. The State of Kentucky regularly stocks the river with rainbow trout (*Salmo gairdneri*) and brown trout (*Salmo trutta*). The more extreme flow fluctuations from Wolf Creek Dam associated with hydropower modification may have a detrimental effect on fish habitat in the tailwater and receiving stream. Reduced flows during nongeneration and

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

increased flows during generation under the proposed modified release schedules may limit fish habitat during some part of the generation cycle. In addition, highly fluctuating flows associated with peaking operation may result in increased bank sloughing in the Cumberland River, further affecting fish habitat.

4. The ORN is considering a variety of measures to reduce the downstream effects of proposed hydropower modifications at Wolf Creek Dam. Construction of a reregulation dam downstream of Wolf Creek Dam at approximately RM 450.70 has been considered to reduce the downstream effects of extreme increases in maximum generating flows. The effects of reregulation on trout habitat downstream of the proposed reregulation dam were evaluated by Martin, Curtis, and Nestler (1985). Predicted effects of reregulation on trout habitat within the reregulation pool were described by Curtis, Nestler, and Martin (1987).

5. As an added alternative, ORN is considering uprating existing generating facilities without reregulation. Uprating would replace existing turbines with new units having a higher capacity but would not increase the number of units beyond those presently in the powerhouse. The new units will have a different release schedule than the existing units because of their higher capacity. The effects of hydropower uprating on downstream trout habitat have not been assessed.

Objectives

6. This report assesses the effects of hydropower uprating on trout habitat downstream of Wolf Creek Dam. Three hydrologic conditions are assessed:

- a. Low inflows (drought or dry weather conditions; flows exceeded 90 percent of the time; September 1983 was selected by the ORN as being representative of this hydrologic condition).
- b. Normal operation (50-percent exceedance).
- c. High inflow (flood potential; flows exceeded 10 percent of time).

This report contrasts predicted trout habitat downstream of uprated facilities with predicted habitat under existing conditions for each hydrologic condition to assess habitat change associated with hydropower uprating. In addition, this information can potentially be used to develop future

operational guidelines to minimize the detrimental effects of hydropower uprate. Release hydrographs representative of each hydrologic condition for existing and uprated facilities were used as the basis of the habitat assessment. The life history stages targeted in this study include juvenile brown trout, adult brown trout, and adult rainbow trout.

PART II: METHODS AND MATERIALS

General Approach

7. An examination and evaluation of the issues related to the proposed Wolf Creek Dam hydropower optimization indicated that, with some modification, the Physical Habitat Simulation System (PHABSIM) developed by the Aquatic Systems Branch (formerly the Instream Flow Group), US Fish and Wildlife Service (USFWS), could be used to predict available trout habitat in the Cumberland River downstream of Wolf Creek Dam. The PHABSIM was selected for the following reasons:

- a. It is generally accepted by many agencies as a defensible assessment method.
- b. The form of the results of an instream flow study using PHABSIM is amenable to incorporation in studies resolving potential water resources conflicts.
- c. It is incremental. That is, it relates small changes in operation to changes in habitat for target life stages.
- d. It is well documented and supported.
- e. It is flexible. The organization of the system is such that changes can be made easily as the state of the art of fish habitat simulation changes and as additional studies provide more information to the analysis.

PHABSIM Description

Background

8. The PHABSIM system is based on the observation that most species of fish prefer certain combinations of depth, velocity, and cover and tend to avoid other combinations of these parameters. If the relative values of different depths and velocities for each species are known and the hydraulic conditions within the channel can be described for varying discharges, it is possible to determine both the quality and quantity of habitat for each fish species at the different discharge schedules. Thus, the instream flow study consists of three essential steps. The first step involves the description of the depth, velocity, and cover available in the river at discrete discharges. The second step is the development of criteria for each species of fish. The third step is to combine steps one and two for the discharge values of

interest to derive an estimate of the value (or worth) of the river for each fish species at each discharge. Depending upon the problem at hand, the user may choose a number of options to complete the analysis. Succeeding sections detail how these general steps were applied to the Cumberland River study.

Suitability curves

9. Suitability curves (or criteria) must be identified or generated to relate cell-by-cell flow conditions in the study reach to usability by a target life stage. That is, the value of hydraulic conditions represented by cell (i) for a particular target species or life stage can be assessed if the criteria (the preference value of different velocities, depths, and substrates) are either known initially or identifiable with further study. Curves of trout life stages used in the Cumberland River study are provided as Appendix A. Note that the range of potential values varies from zero (no value or preference) to one (optimal conditions or preference) for each variable. The suitability curves in Appendix A were obtained from Nestler et al. (1986). These curves were selected because the races of trout stocked, geographical location, channel size, and discharge patterns are generally similar for the Cumberland River and the system evaluated by Nestler et al. (1986). The use of these curves on the Cumberland River was coordinated with both the Kentucky Department of Fish and Wildlife Resources and the USFWS Ecological Services, Cookeville Office.

10. The criteria values for each variable can be combined in several ways to generate a single value of usability (a weighted factor) for the velocity, depth, and cover conditions in each cell. The most commonly used method (and the default option in PHABSIM) to generate this weighting factor is by multiplying the individual suitability values for each variable (velocity, depth, and substrate) to generate a product. For example, if velocity and depth criteria are optimum and the cover criterion is 0.5 within cell (i), the resulting weighted factor for cell (i) = 1.0 × 1.0 × 0.5 = 0.5. Other options for combining suitabilities for depth, velocity, and substrate/cover are available and, if necessary, the code of PHABSIM can be modified. For most applications of PHABSIM (and for this evaluation of Wolf Creek Dam), depth, velocity, and cover are assumed to be independent variables, even though these variables are known to be correlated (Dingman 1984). If necessary, bivariate representations can be used (Gore and Judy 1981); however, onsite data must be collected to develop the bivariate suitability criteria since almost all

published suitability curves present depth and velocity information as independent variables. Additional information on different ways of combining individual suitability curves to generate a composite suitability or weighting value can be obtained from Milhous, Wegner, and Waddle (1984). Additional information on interpreting, evaluating, and generating suitability curves can be found in Bovee (1986).

Estimating habitat

11. In a typical application of PHABSIM, values for depth, velocity, and substrate in cell (i) are each evaluated relative to the criteria for the target life stage to generate a weighting factor for the surface area of the river represented by cell (i):

$$W(i) = suit(d) \times suit(v) \times suit(c) \tag{1}$$

where

W(i) = weighting factor for cell (i)

suit(d) = suitability of the depth in cell (i) for a given discharge for the target species life stage

suit(v) = suitability of the velocity in cell (i) for a given discharge for the target species life stage

suit(c) = suitability of the cover in cell (i) for the target species life stage

12. The amount of river area available for a target life stage in cell (i) can be represented as

$$WUA(i) = area(i) \times W(i) \tag{2}$$

where

WUA(i) = weighted usable area of the river surface represented by cell (i)

area(i) = area of the river represented by cell (i)

W(i) = weighting factor for cell (i)

13. The total weighted usable area (WUA) in the study reach available for use by the target life stage for a given discharge can then be represented as the sum of the weighted areas of each cell, or

$$WUA(t) = \sum_{i=1}^{n} WUA(i) \tag{3}$$

where

$WUA(t)$ = total WUA for a given life stage

n = number of cells in the river reach

This formulation allows estimation of a single habitat value that is a function of discharge for the target life stage. Habitat values available at other discharges are calculated in a similar manner to generate an available habitat versus discharge relationship.

14. The discussion above presents only the most fundamental underpinnings of PHABSIM. Many other techniques, options, and programs are available that provide for complete analyses of water development projects, including comparisons of different operational and structural alternatives, time series analysis, and other types of habitat analyses. The interested reader should consult various Instream Flow Information papers, particularly those of Bovee (1982) and Milhous, Wegner, and Waddle (1984).

Simulation Strategy

Background

15. The standard version of PHABSIM recommended by the USFWS for relating fish habitat to reservoir project operations was considered inadequate for the Cumberland River application because it is restricted to predictions under steady-state or gradually varied flow conditions. A model that could interface fish habitat requirements and hydraulic conditions under dynamic flows was needed for predictions on the Cumberland River under peaking conditions. Under dynamic flow conditions, the peak release associated with hydropower production attenuates, and the base flow increases as the flows move downstream (Appendix B). Thus, steady-flow hydraulics are usually inadequate since the discharge at the dam may not reflect conditions at points downstream of the dam. Additionally, hysteresis may occur as the stage rises and falls because of backwater effects.

16. The best method of hydraulic simulation within PHABSIM for constant flow conditions (Appendix L of Milhous, Wegner, and Waddle 1984) is described

below followed by a discussion of modifications of this method to simulate trout habitat under dynamic flow conditions.

Habitat simulation under
steady-state conditions

17. Within PHABSIM, a step backwater hydraulic program, Water Surface Profile (WSP), is used to predict water surface elevations (stage levels) at different discharges for separate cross sections in a river reach with steady, nonuniform flows. The stage-discharge information calculated by WSP is then passed to the IFG-4 program. It should be noted that the output of HEC-2 (US Army Engineer Hydrologic Engineering Center 1982) or any other steady-state hydraulic model can be substituted for the WSP program to provide stage-discharge information necessary for a PHABSIM analysis. Additionally, stage-discharge information can be obtained from gaging stations established at cross sections in each study reach.

18. The IFG-4 program takes the stage-discharge information and partitions the flow into a series of lateral cells at each cross section. Several options within IFG-4 are available to generate cell depth and velocities for a given stage and discharge.

19. If measured velocities are not available, the program separates the total discharge into cells based upon the hydraulic radius of each cell. For constant cell widths, this formulation results in deeper cells having higher current velocities. This option is useful for predicting flow patterns in simple, straight channels. Flow patterns at cross sections located on bends or with complex channel morphology (braided channels, etc.) cannot be adequately described using the hydraulic radius alone to partition the total flow into cells.

20. Velocity measurements made in the field under constant discharge can be used to calibrate the IFG-4 program. In this case, the known laterally varying velocities are used to solve Manning's equation for bed roughness (Manning's n) for each lateral cell since all other variables are known. The calculated cell-specific "n" value is then used to generate depths and velocities in each cell at all simulated discharges. After estimating a lateral flow pattern, IFG-4 checks the calculated water surface elevation against the given water surface elevation provided by WSP or similar programs and then, if needed, modifies all cell velocities by a common factor to raise or lower the calculated water surface elevation until it matches the elevation provided by

WSP. Obviously, calibration of the IFG-4 program to field-measured velocities is superior to using the hydraulic radius for estimating lateral flow patterns. However, caution must be exercised in selecting a calibration flow. A lateral velocity pattern observed in a low-flow situation may not be accurate at high flows since substrate material (high roughness) will influence velocity patterns more at low discharges than at high discharges. If field inspection of the cross section indicates a likely shift in flow pattern with discharge, multiple velocity calibration data sets may be required.

Habitat simulation under dynamic flow conditions

21. Conceptually, the Cumberland River analysis by PHABSIM under dynamic flow conditions was similar to the approach discussed in the previous section, except that the WSP model was replaced by a one-dimensional dynamic flow model, BIRM (Branched Implicit River Model) (Johnson 1982, 1983). It should be noted that the stage-discharge pairs provided by the dynamic flow model are time-varying. Thus, the final results of the analysis for a single cross section are presented as habitat available per time increment rather than habitat as a function of discharge, as is usual in instream flow analyses. Each time increment has a specific discharge (as determined by hydraulic simulation) associated with it. The dynamic flow model is used to pass time-varying stage-discharge information to the IFG-4 program of PHABSIM. No further modifications of PHABSIM were required for the Cumberland River analysis. The unsteady flow code (BIRM) used in this application can be replaced by any other dynamic, one-dimensional riverine hydraulic code that is capable of providing stage-discharge information to the IFG-4 program. The BIRM output needed to drive the fish habitat model was provided by the Hydraulics and Hydrology Branch of the ORN.

Flow and Channel Description

Site description

22. The river reach investigated in this study was bounded upstream by Wolf Creek Dam (RM 460.9) and downstream at a cross section near the bridge crossing the Cumberland River at Burkesville, KY (RM 427.8). Preliminary analysis of the Burkesville cross section by Instream Flow Incremental Methodology (IFIM) procedures indicated that this cross section represented an area

at which loss/gain in trout habitat between present and projected releases was relatively small (<5 percent). Channel cross sections used in this study were surveyed in April 1985. These cross sections were initially used by ORN to perform the hydraulic simulation necessary to design a possible reregulation dam and to determine the elevation and capacity relationship of the reregulation pool. (See Curtis, Nestler, and Martin 1987 for details.) The 36 cross sections listed below (designated by river mile) were selected for IFIM analysis. (Cross-sectional plots are presented in Appendix C.)

460.00	459.26	457.40	457.16	455.90	455.10
454.70	453.18	452.76	451.70	451.20	450.95
450.26	449.40	448.50	448.07	447.35	446.99
445.38	444.79	443.78	443.38	443.04	442.16
441.02	440.25	439.94	438.88	437.34	435.43
433.64	432.50	431.42	430.41	428.64	427.80

23. The reach of the Cumberland River investigated in this study is generally representative of a large, upland river flowing through rugged terrain. The slope is moderate, approximately 3 ft per mile (0.06 percent). Channel widths at a discharge of 4,000 cfs vary from 200 to 500 ft. River elevation at the middle of the reach is about 535 ft. Substrate is composed primarily of rubble, cobble, and occasional boulders and bedrock shelves near the steeper banks, with gravel predominating in the center of the channel. Sand bottoms along the banks and gravel beds in the thalweg are most common farther downstream (RM 440 and downstream).

Field methods

24. Velocity calibration data. Cell-by-cell velocity information was required to develop the velocity calibration data set. Velocity information was collected 21-23 August 1985 by field crews composed of representatives of the US Army Engineer Waterways Experiment Station (WES), ORN, USFWS, and the Commonwealth of Kentucky. The field crews relocated previously surveyed cross sections by surveying from established points (usually a head pin) following the field notes of the original survey party. Once the channel cross sections were relocated, channel coordinates were relocated using an 880-ft, 0.125-in. wire-cable tag line. The tag line was secured to the riverbank, unreeled across the Cumberland River using a 16-ft johnboat (flat-bottomed), and tightened using a "come-along." Each cross section was first surveyed using a

Lowrance depth finder to provide a continuous record of the cross section and to locate substantial changes in the bottom profile. The work boat was hand secured to each of the cross-section coordinate points, and a velocity measurement was made using a Marsh-McBirney current meter. Velocity was recorded after the meter reading had stabilized. Velocity measurements were initially made at 2/10 and 8/10 depths; however, because of time constraints, most velocity measurements were made at 6/10 depth (measured from the water surface). Generally, at least 20 verticals were measured at each cross section. Discharge from Wolf Creek Dam was approximately 4,000 cfs during most of the survey.

25. Velocity calibration data were collected for cross sections 460.00, 459.26, 457.4, 457.16, 455.90, 455.10, 454.70, 453.18, 452.76, 451.70, 451.20, and 450.95. These are all upstream cross sections near Wolf Creek Dam and received the greatest fluctuations in stage and habitat from peaking operations and, therefore, required more critical calibration data to better simulate habitat conditions. For cross sections farther downstream, BIRM output and surveyed cross-sectional information were combined with recorded cover codes to simulate cell-by-cell depth and velocity relationships.

26. Cover code. Cover codes for each transect were recorded on 14-15 March 1987 by personnel from WES and Tennessee Technological University. The cover code (channel index) system used by Nestler et al. (1986) for the Chattahoochee River was applied to the Cumberland River system. Descriptions of the cover codes are given in Table 1.

Selection of simulation time period

27. Simulation of habitat under dynamic flow conditions is complicated by the temporal and spatial diversity of flow conditions experienced by fish. That is, flow conditions can change hourly and longitudinally because of varying discharges from Wolf Creek Dam. Representative time-varying discharges (of 120-hr periods) for six operating schedules were provided by ORN to WES. These operating schedules included release scenarios for both existing and uprated facilities and under the three hydrologic conditions described in paragraph 6.

28. Limitations in the PHABSIM software precluded evaluating each 120-hr release schedule. However, examination of the hydrographs revealed that shorter intervals, representing weekday and weekend releases, could be simulated. Thus, simulation of hours 37 through 107 at RM 460.0 includes

Table 1

Channel Index fcr Trout Used on the Cumberland River

Channel Index	Suitability Value	Description
1.0	0.10	All sand - no cover
1.5	0.15	Gravel - no cover
2.5	0.25	Sand - some cover
3.0	0.30	Sand - extensive cover
4.0	0.40	Gravel - extensive cover
5.0	0.50	Cobble (3-10 in.) - some cover
6.0	0.60	Boulder - some cover
7.0	0.70	Bedrock - some cover
8.0	0.80	Cobble - extensive cover
9.0	0.90	Bedrock - extensive cover
10.0	1.00	Boulder - extensive cover
11.0	1.50	Upland vegetation

representative weekday discharges and weekend discharges. A 24-hr simulation period was used to represent the high inflow (10-percent exceedance frequency) because the daily release schedules were identical for the weekly hydrograph provided by ORN.

29. The 36 cross sections used in this study were combined into three groups of 12 cross sections for clarity and brevity of presentation and computational convenience. Group 1 consists of cross sections 460.0 through 450.26, group 2 consists of cross sections 449.4 through 439.94, and group 3 consists of cross sections 438.88 through 427.8.

30. Time periods analyzed for each group per hydrologic condition were varied to account for the travel time associated with the release surge as it moved downstream. For example, simulations for 10-percent uprate conditions were run between hours 30 and 54 for group 1 (nearest the dam), between hours 32 and 56 for group 2 (middle group), and between hours 36 and 60 for group 3 (farthest downstream). Time intervals were chosen by examination of stage and discharge information obtained from ORN for representative cross sections (Appendix B). Discharges ranged from 800 to 38,000 cfs.

31. Riverflow downstream of Wolf Creek Dam during nongeneration is determined by backwater effects and by nonrelease inputs such as tributaries,

surface runoff, bank storage, and leakage. Based on several field measurements, inputs to the Cumberland River other than discharge were estimated by ORN to be approximately 800 cfs. Consequently, a minimum discharge of 800 cfs from Wolf Creek Dam was used in the model by ORN both as an estimate of nondischarge inputs and to avoid numerical instabilities in the hydraulic model. However, under dry conditions, the 800-cfs value may overestimate nonrelease inputs. Field measurements on 15 March 1987 at RM 450.95 (about 10 miles downstream from Wolf Creek Dam), following an extended period of nongeneration, yielded a discharge of 1,149 cfs. Although this discharge was substantially above the 800 cfs used as a minimum discharge from the dam, it was also about 150 cfs below the value predicted by BIRM for this cross section using the flow scenario most similar to the 15 March conditions. Consequently, it was concluded that the minimum-flow value of 800 cfs may overestimate nonrelease inputs, particularly near the project and under low rainfall conditions. The 800-cfs value is probably an adequate estimate of nonrelease input at some point farther downstream of RM 450.95 and under normal rainfall conditions.

32. This question probably has minimal impact on study predictions for two reasons. First, uprate conditions have different maximum release rates but the same minimum releases. Consequently, the downstream impacts of the uprated facilities and the existing facilities are similar during periods of nongeneration. Second, limiting habitat conditions for trout during nongeneration periods are not low-flow conditions but low-stage conditions. Since the Cumberland River in the most upstream group of cross sections is composed primarily of large, deep pools, the effects of overestimating minimum flows probably has minimal effect on habitat predictions.

Model Implementation

33. The reach for hydraulic simulations consisted of 74 cross sections extending from RM 460.9 (Wolf Creek Dam) to RM 423.46 (downstream of Burkesville, KY). Hydraulic simulations using BIRM were conducted by ORN for all six scenarios for time periods representing typical weekday and weekend generation schedules. Stage-discharge pairs were obtained for all six scenarios from the above hydraulic simulations. Use of the BIRM model is described by Johnson (1983). Curtis, Nestler, and Martin (1987) describe procedures to link a dynamic flow model to a habitat model.

PHABSIM implementation

34. Implementation of PHABSIM required the execution of two models--IFG-4 and HABTAT. The necessary information for IFG-4 input data sets included distance-elevation coordinate pairs, cover codes, stage-discharge pairs, and velocity calibration data for each cross section. Channel geometry information was provided by ORN and field measurements. Velocity information and cover codes were obtained by field measurement. If velocity calibration data were unavailable (downstream of RM 444.50), IFG-4 defaulted to calculation of velocity from the hydraulic radius as described earlier. A separate input data set was generated for each cross section.

BIRM-PHABSIM linkage

35. The BIRM and PHABSIM, when coupled together, were used to determine the effects of peaking operation on tailwater habitat. The BIRM was executed to create the stage-discharge pairs for IFG-4. The IFG-4 program generated a distribution of velocities and depths across each cross section, one distribution for each stage-discharge pair at hourly stage and discharge updates. After predicting the velocity and depth distributions across a cross section, IFG-4 passed this information to the HABTAT program, in which cell-by-cell conditions were evaluated relative to the habitat suitability criteria of the target fish species. The result of HABTAT was expressed as the amount of available habitat for each targeted species for each specific time/discharge.

PART III: RESULTS

Interpretation of Results

36. The results of PHABSIM analyses are ordinarily presented in terms of WUA per specified length of river. Weighted usable area is defined as the surface area of river providing habitat for target fish species.

37. The results of this analysis are presented in a variety of forms. Summary plots, with total habitat per section, are presented as WUA as a function of time. These presentations will give an idea of the overall trends under different scenarios. Intergroup comparisons can give an idea of the effect of attenuation of the peaking surge, since discharge can vary throughout the reach as the power wave attenuates and the base flow increases as the wave moves downstream.

38. The results are also presented by individual cross-sectional plots of WUA and time for each of the three groups. In this way, intragroup comparisons can be made to assess the habitat value of specific areas within the simulated reach.

39. Finally, habitat information is presented as minimum habitat available (WUA) during each simulation for each cross section of each grouped stream reach. This is probably the most meaningful presentation of the results, since it approximates limiting habitat conditions.

40. Results in this report are presented in terms of WUA per 1,000 ft of river. This representation allows direct comparison of cross sections, even if the length of river that each represents varies. It also allows an accurate depiction of the habitat effects due to dynamic flows at each cross section.

41. Three-dimensional plots of individual cross sections for each group for all scenarios are included in Appendix D. Note that the axes on the summary and individual plots differ from the habitat discharge plots ordinarily associated with an instream flow study. In this case, the axes are habitat as a function of time, with each point on the ordinate representing the habitat available at the cross section for the flow conditions at that time. For the sake of brevity, plots for individual cross sections are not discussed in the text.

42. The WUA values presented in the results can be proportionally

related to channel width by dividing by 1,000 (or 304.8, if metric) and dividing by channel width. For example, if WUA is 200,000 sq ft (18,580.6 sq m), then the proportion of river area available is 200,000 (18,580.6) divided by 1,000 (304.8) divided by, say, 400 (121.9 m) (channel width), which yields a value of 0.50. Thus, approximately half of the river channel is available for habitat under the conditions examined.

43. Results are also presented in summary form by multiplying the length of river that each cross section represents (the reach multiplier) by the WUA per 1,000 ft (Appendix E). Habitat values represented by each cross section are then summed to generate a total reach summary. These results are presented for minimum and average habitat available for each target species. The reader must be aware that considerable detail is lost in the course of summarizing the effects of dynamic flow conditions. For further information concerning the relationship between river surface area and suitability, the reader is referred to Bovee (1982).

Relative Flow Conditions

44. The relative flow conditions under each hydrologic scenario are summarized in the following text. Plots of stage and discharge versus time for each scenario (Appendix B) can be examined to obtain more detailed information.

September - existing

45. Under existing low-flow (September) release schedules, discharge varies from 800 to 24,000 cfs during weekday generation with a duration of about 5 hr. Weekend generation is of lower discharge and duration. Along with discharge, elevation change between generation and nongeneration attenuates as the peak passes downstream from 15.8 ft at RM 460 to 8.9 ft at RM 449 (Rock House) to 6.2 ft at RM 438 (upstream of Burkesville, KY).

September - uprate

46. September uprate conditions call for decreased discharges ranging from 800 to 22,400 cfs but with a duration of 6 hr. Under these uprate conditions, stage differences varied from 16.5 ft near Wolf Creek Dam (RM 460) to 6.6 ft near Burkesville during weekday operations. Again, weekend operations included decreased discharge and duration of releases.

Average - existing

47. Under average existing release patterns (50-percent exceedance), discharge patterns varied from 800 to 27,000 cfs with a duration of 10 hr during weekdays. Weekend patterns varied only in duration, 9 hr (4 hr of partial generation) on Saturdays and 6 hr (3 hr of partial generation) on Sundays. Average discharge patterns resulted in stage differences of 19.7 ft near Wolf Creek Dam attenuated with distance to 14.1 ft at RM 438.

Average - uprate

48. Under uprate conditions, amplitude of discharges increased with releases from 800 to 36,600 cfs with a duration of 9 hr. However, 4 hr of this scenario was under partial generation. Weekend generation varied only in duration of releases: 6 hr on Saturday (2 hr partial) and 4 hr on Sunday (2 hr partial). Stage differences varied from 23.2 ft near the dam to 15.3 ft at RM 438.

Potential flood - existing

49. During potential flood conditions (10-percent exceedance), existing release schedules call for the same release schedule on all days of the week, varying from 800 to 30,000 cfs with a duration of 20 hr. This results in stage differences of 22 ft near Wolf Creek Dam dropping to 21 ft at RM 438.

Potential flood - uprate

50. Uprate conditions call for increased releases, varying from 800 to 38,000 cfs, for a shorter duration of 15 hr. The uprated schedule results in changes in water surface elevation of 25.5 ft near the dam, dropping to 23.3 ft at RM 438, upstream of Burkesville.

Existing Release Schedules

General results

51. Under existing conditions, the predicted habitat availability for brown and rainbow trout is quite similar. In most cases, habitat for each species was at a minimum during highest discharges and at a maximum during the lowest flow periods (about 800 cfs). In the upper and middle reaches of the river, more brown trout habitat is available than rainbow trout habitat at all discharges (see summary plots, Appendix D). However, in the lowest cross sections examined (upstream of Burkesville), this situation is reversed, except for 10-percent exceedance conditions, with more rainbow trout habitat

available. This is probably due to the constant availability of some current velocity that favors rainbow trout (see suitability criteria, Appendix A).

52. There is a slight rise in rainbow trout adult habitat during the first hour of a peaking release. This is an anomaly reflecting the fact that peak value of velocity suitability for rainbow trout is slightly higher than 0 fps (Appendix A). Thus, there is a very short period of time in which more habitat appears to be created during the rising arm of the peaking release. This increased habitat is short lived and declines to minimum values as the peaking release continues and the stage and velocities also increase.

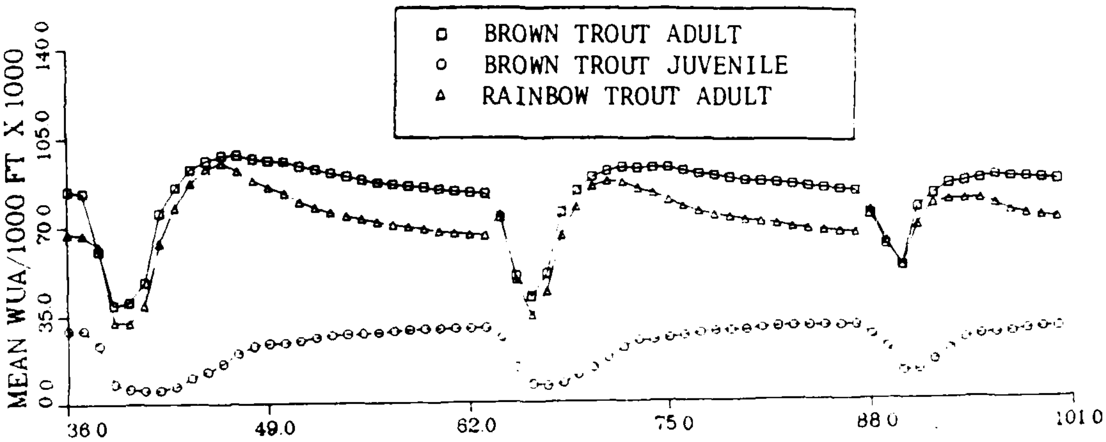
53. Habitat availability for juvenile brown trout is minimal during low flows and declines during peaking releases. Near Burkesville, the impact of peaking releases upon juvenile brown trout is not noticeable.

Brown trout adults

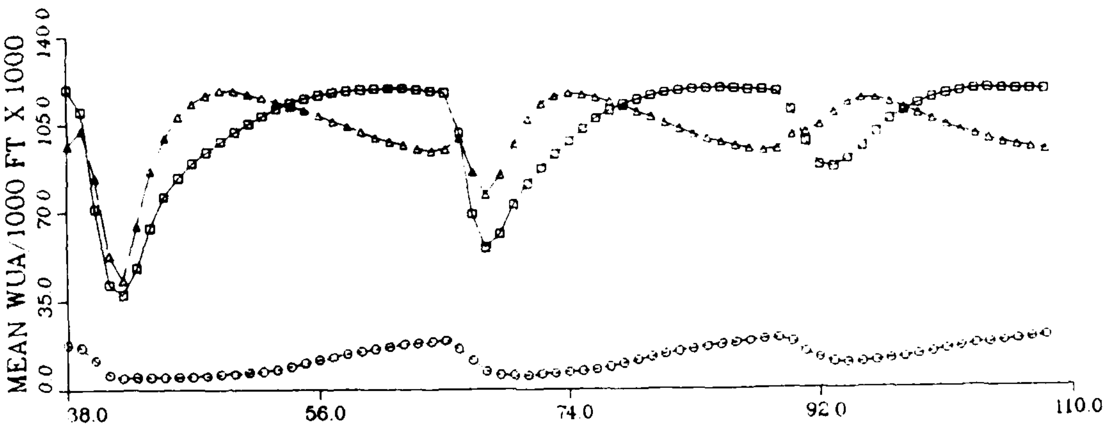
54. Habitat for adult brown trout under existing conditions varies both by distance and over time. In general, over the 32.2 river miles of simulation, the middle 10 miles (RM 449.4 to 439.94) appear to contain the greatest amounts of usable habitat area. The lower reaches of the river contain the smallest amounts of suitable habitat.

55. Habitat varies substantially with changing discharge. Available habitat is minimal during peak discharges from Wolf Creek Dam, often less than 30 percent of low-flow values (see Figures 1-3). Some transects have virtually no usable habitat during these generation periods (see Appendix D). No substantial change in available habitat was observed during 10-percent exceedance operation at the most downstream river sections analyzed. Habitat value remained low during low and peak discharge periods.

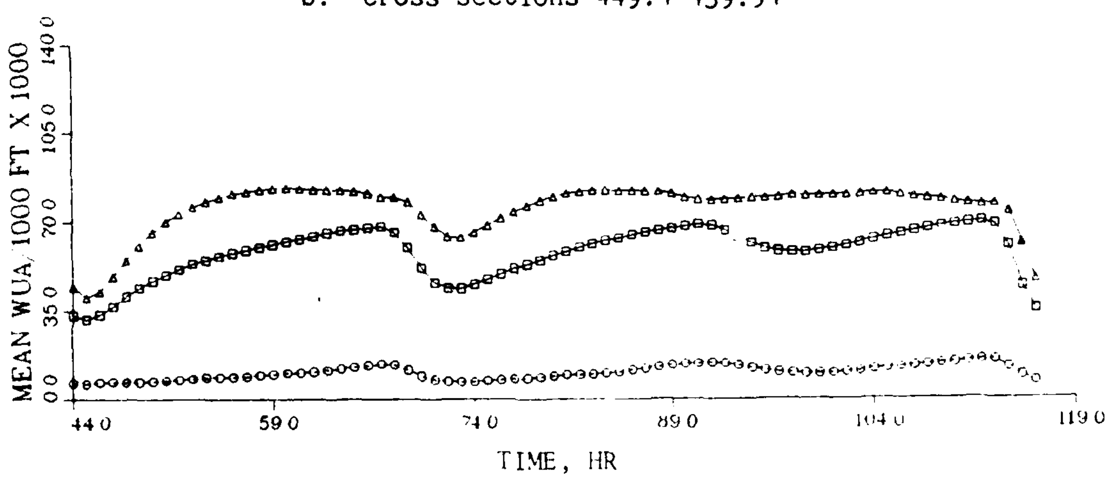
56. Although three-dimensional plots of time-varying habitat are the most complete and comprehensive representation of hydropower operation effects on trout habitat, the quantity and complexity of output that must be assessed are not conducive to formulating general statements of impact. For example, ranking the hydrological-operational scenarios from least impact to most impact on trout habitat is not possible because of the detail in the three-dimensional representation of the data. The following options are available for integrating the effects of changing habitat during a generation cycle into a single value of impact that can be used to summarize the effects of each operational and hydrological scenario.



a. Cross sections 460.0-450.26

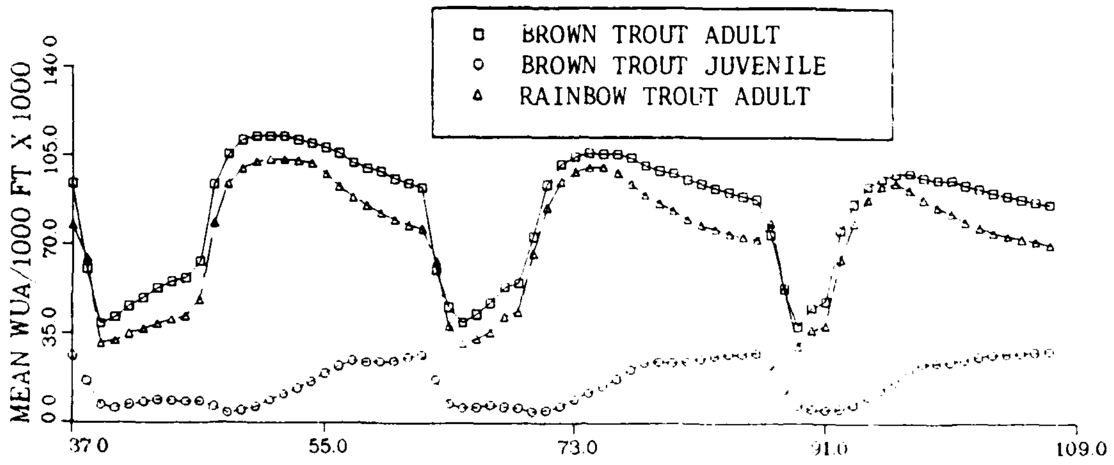


b. Cross sections 449.4-439.94

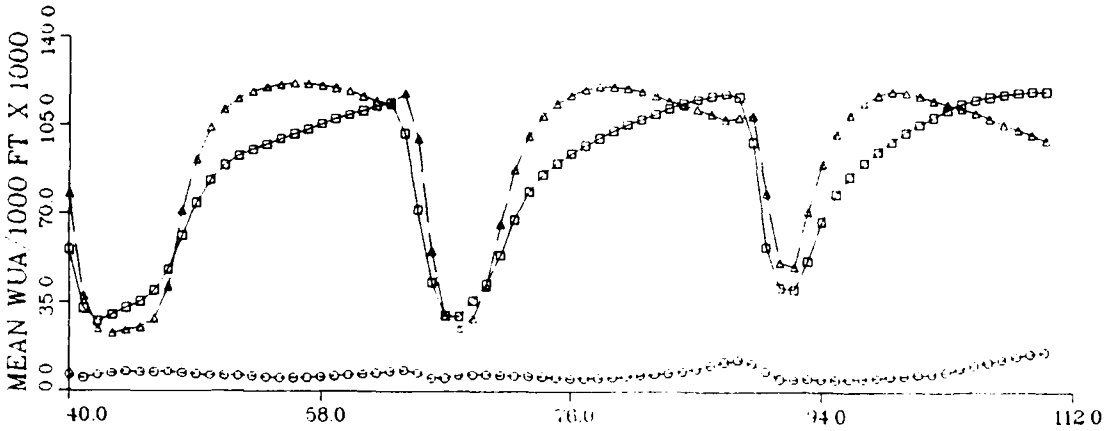


c. Cross sections 438.88-427.80

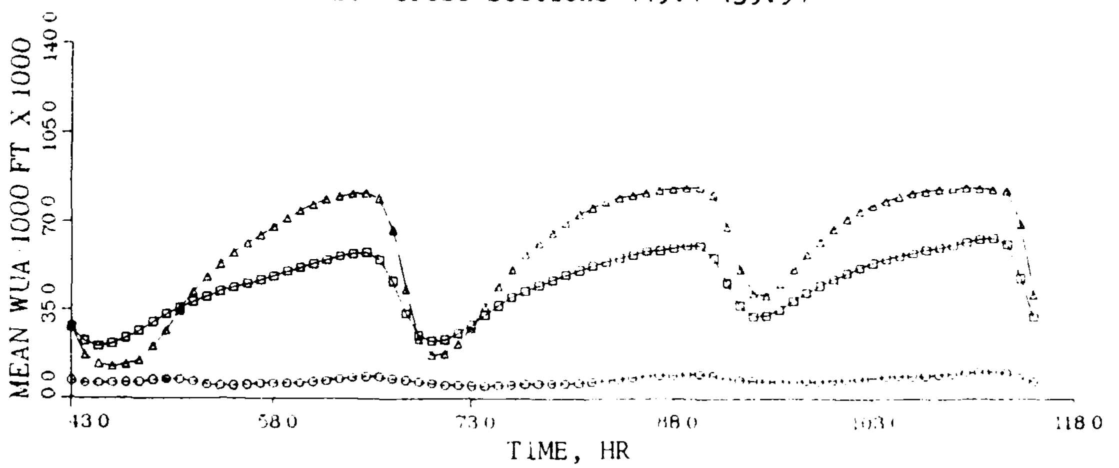
Figure 1. Mean habitat available during weekday and weekend release schedules, September existing conditions



a. Cross sections 460.0-450.26

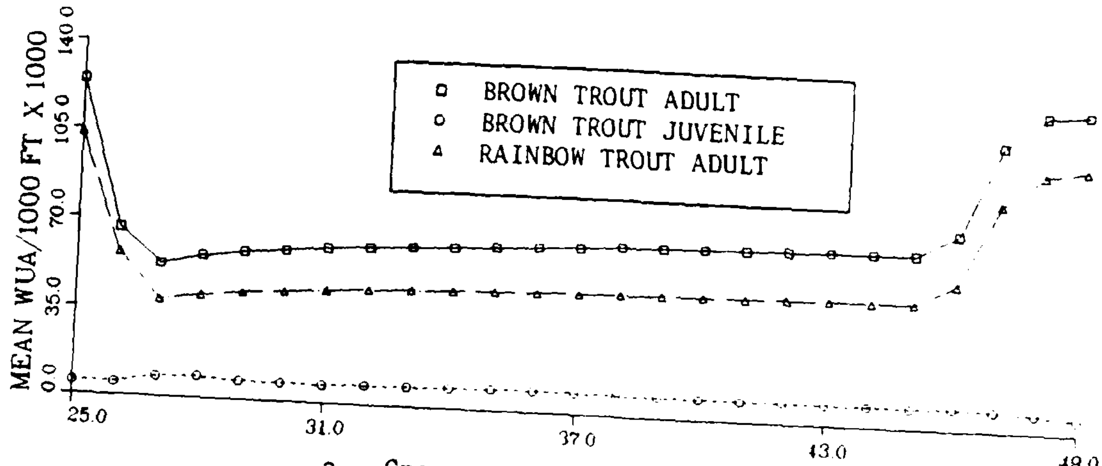


b. Cross sections 449.4-439.94

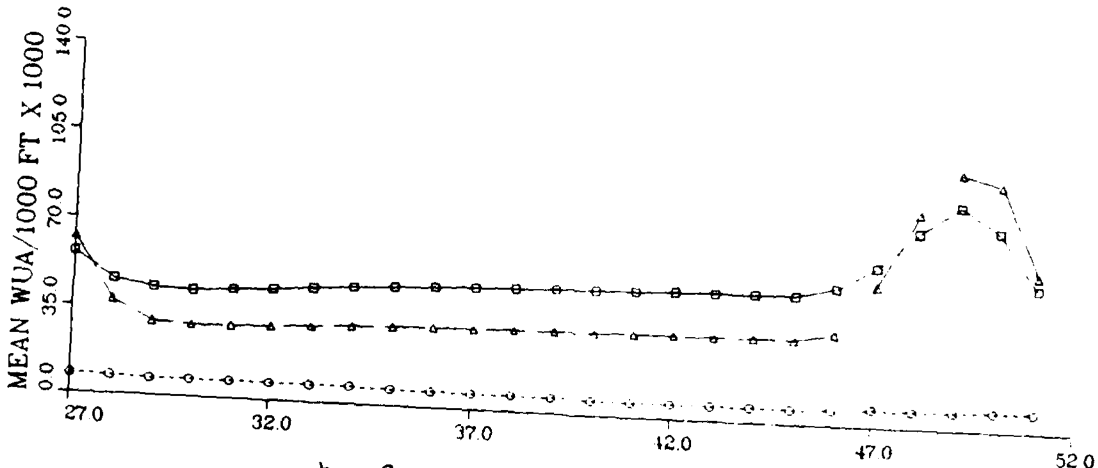


c. Cross sections 438.88-427.80

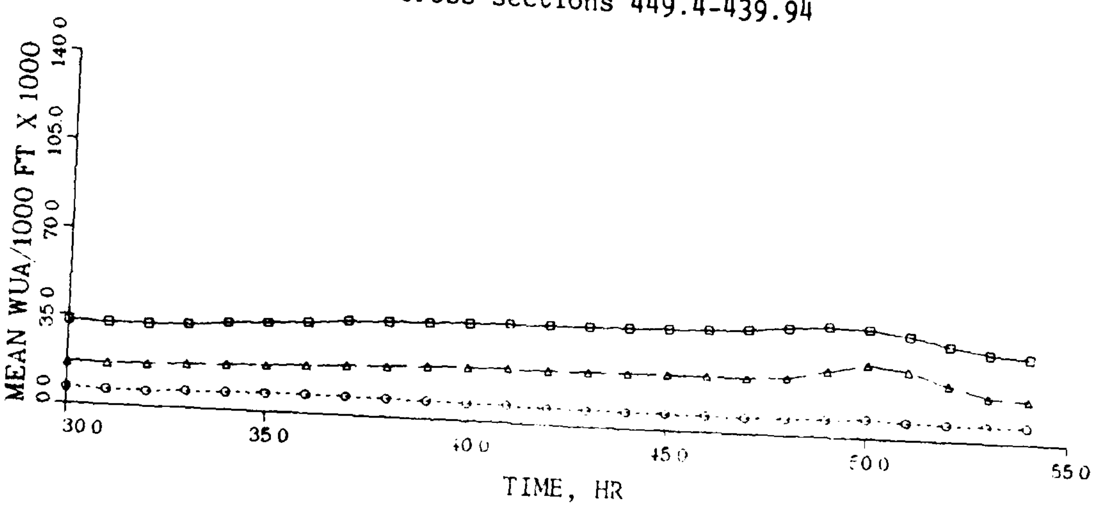
Figure 2. Mean habitat available during weekday and weekend release schedules, 50-percent existing conditions



a. Cross sections 460.0-450.26



b. Cross sections 449.4-439.94



c. Cross sections 438.88-427.80

Figure 3. Mean habitat available during weekday and weekend release schedules (identical for all days), 10-percent existing conditions

a. A summation of the minimum habitat available for each cell within a transect is probably the best method for summarizing the impacts of peaking operation on benthos, fish spawning, and other life stages of aquatic biota that are not mobile. This method is not suitable in this case because trout are mobile enough to move from one cell to another within a transect. Consequently, this method probably underestimates habitat available under dynamic flow conditions.

b. Mean habitat within a transect over a generation cycle is not an adequate measure of habitat availability under dynamic flow conditions because this statistic is not sensitive to limiting habitat conditions under extreme high- or low-flow conditions.

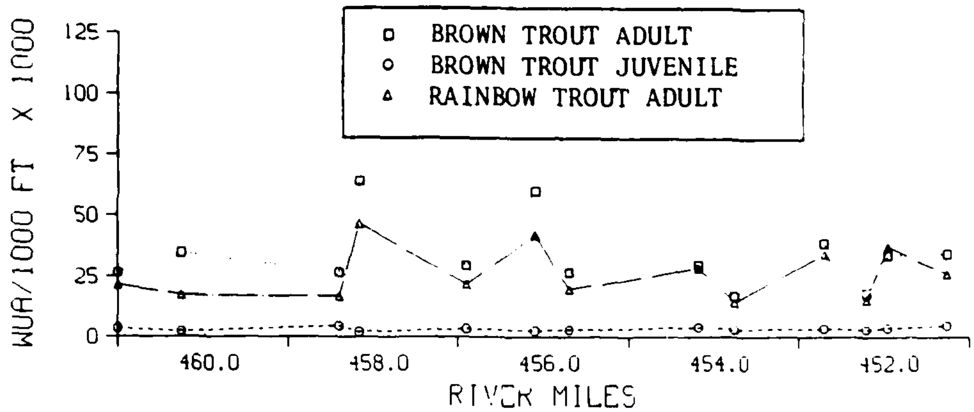
c. The minimum habitat within a transect over a generation cycle is probably the best single measure of impact for relating the effects of peaking on aquatic biota such as trout (Figures 4-6). Conceptually, the habitat minimum probably represents refuge habitat available for fish during the most limiting part of the peaking cycle.

57. Several trends were apparent when the PHABSIM results were presented as habitat minimums. At all transects (see Appendix D), the minimum values occurred during passage of the peaking wave. With the exception of the most downstream river reaches during low-flow scenarios, brown trout had more habitat than rainbow trout during the passage of the power surge. The lowest minimum values remained fairly constant through the length of the river.

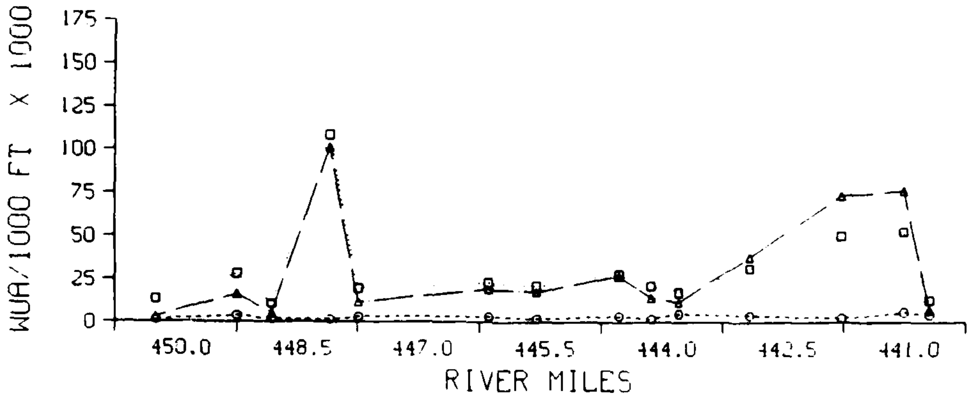
58. The amount of habitat available during peaking operation varied considerably among the transects. In particular, RM 447.35 offered substantially more habitat during peaking operation under all scenarios than the other transects. This particular transect (Appendix C) cuts through a large pool that increases habitat availability for two reasons. First, the large cross-sectional area available to convey the flow at this transect results in reduced velocities that generally do not exceed the tolerances of the trout life stages. Consequently, more of the area of the pool is available for habitat for trout. Second, this cross section is considerably wider than most of the other cross sections evaluated in this study. This increases WUA because the weighting factor operates on the cell top widths. Thus, all other factors being equal, wider cross sections will yield greater increased habitat area.

Brown trout juveniles

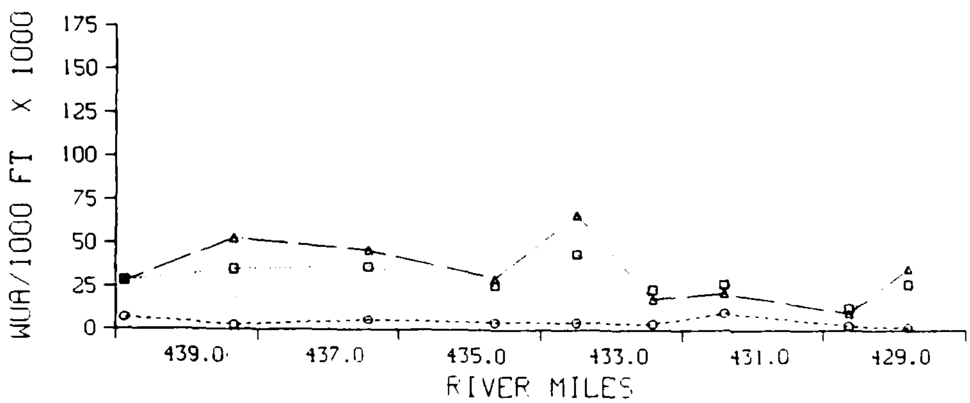
59. The Cumberland River downstream of Wolf Creek Dam provides only a marginal amount of habitat for brown trout juveniles during any type of operational scenario. Under existing conditions, juvenile habitat generally tracks that of adult brown trout, but the amounts available are less than 10 percent



a. Group 1 - simulated hours 36-100

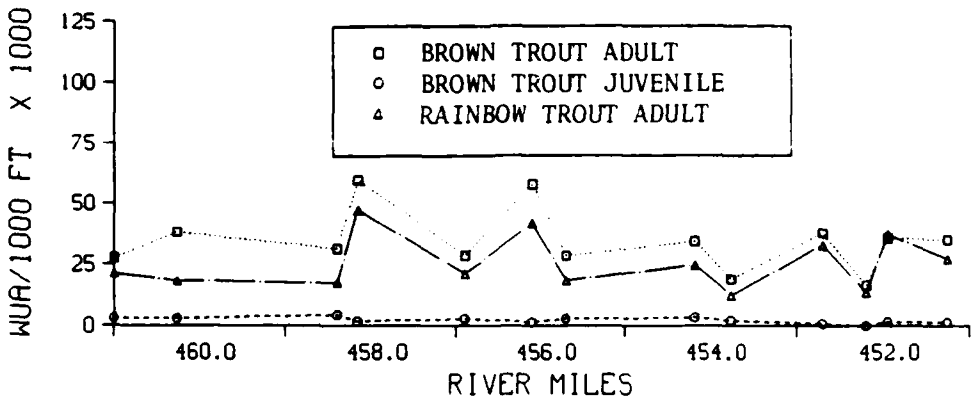


b. Group 2 - simulated hours 38-108

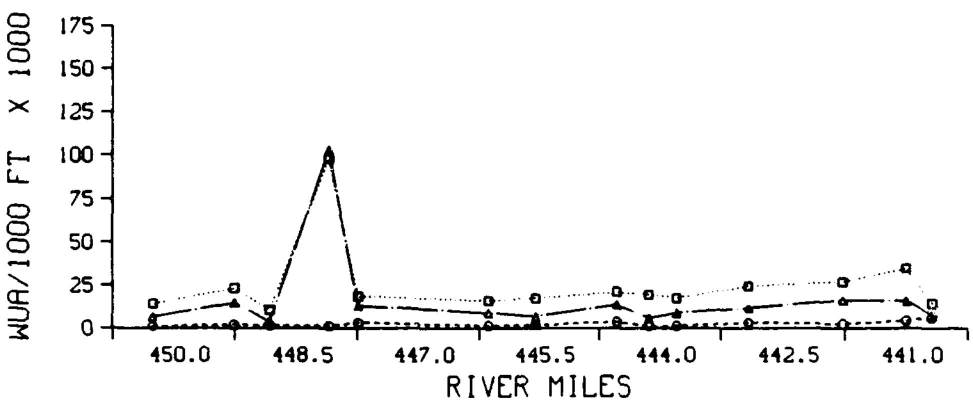


c. Group 3 - simulated hours 44-116

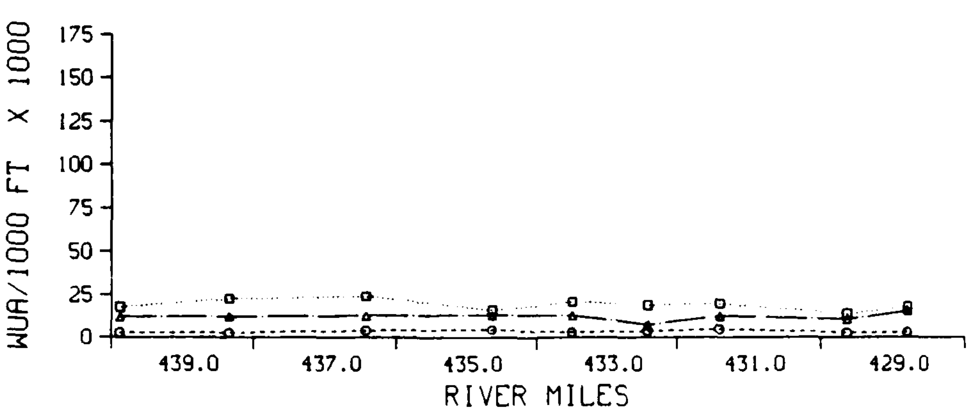
Figure 4. Minimum habitat available at each cross section, September existing conditions



a. Group 1 - simulated hours 37-107

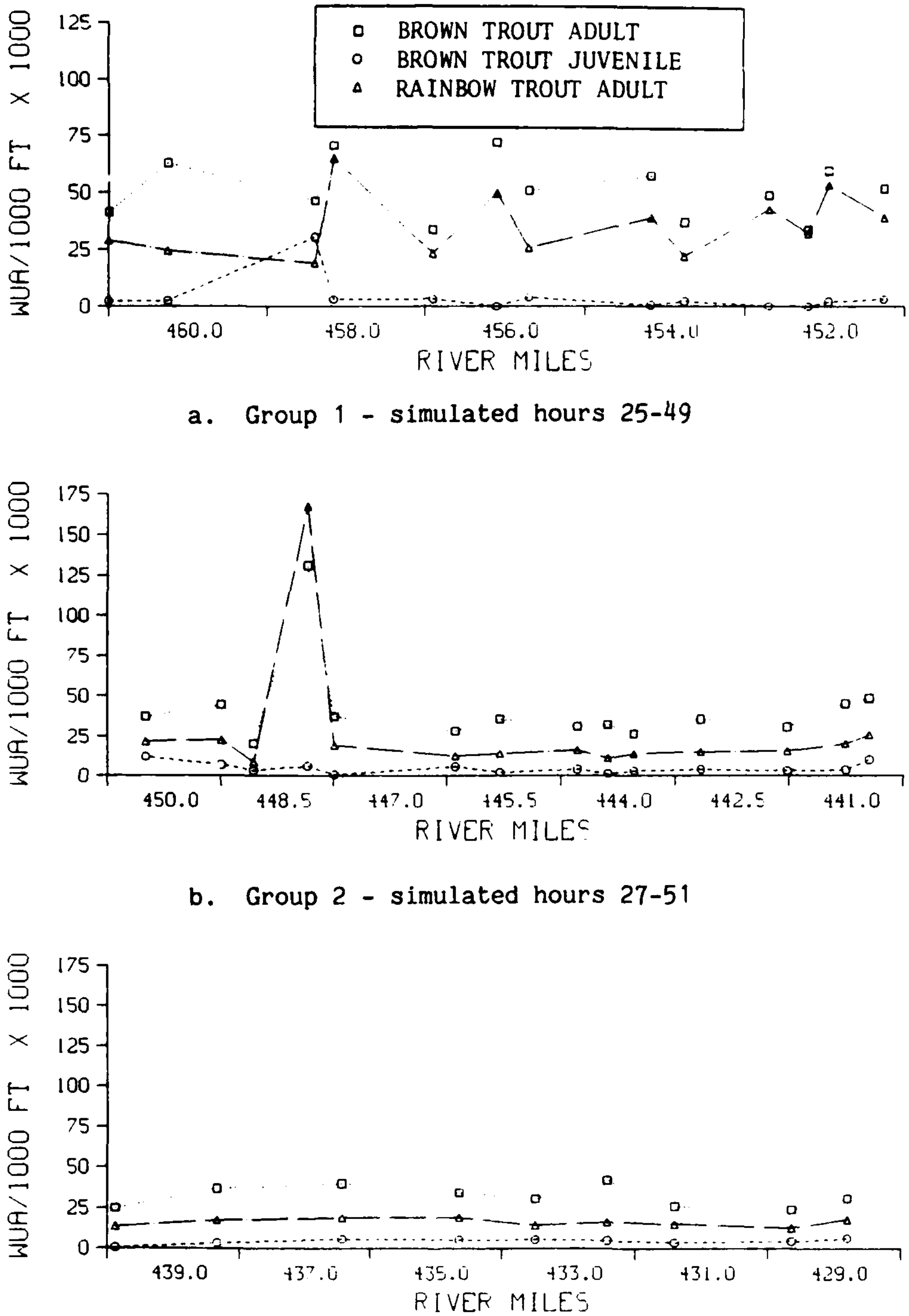


b. Group 2 - simulated hours 40-110



c. Group 3 - simulated hours 43-115

Figure 5. Minimum habitat available at each cross section, 50-percent existing conditions



a. Group 1 - simulated hours 25-49

b. Group 2 - simulated hours 27-51

c. Group 3 - simulated hours 30-54

Figure 6. Minimum habitat available at each cross section, 10-percent existing conditions

of that available for adults. Many transects contain no usable habitat for juveniles. In this analysis, juvenile habitat is restricted to the edges of the river channel since the depth criterion is violated except under the lowest flow conditions. Consequently, peaking operations have relatively little impact on the amount of habitat available to juvenile brown trout, except under low-flow conditions (September) when the velocity criterion (velocities are too low) will also be violated.

60. The results appear to reflect the above considerations. Minimum habitat values remain fairly constant throughout the length of the river analyzed, with no transects appearing to offer greater habitat for juveniles during peaking operations. Indeed, minimum values for juvenile brown trout are close to zero during at least some period of time at all transects during peaking operations.

61. The biological realism of the results for juvenile brown trout is unknown. The results imply that juvenile brown trout must be able to track the water's edge as the water level rises and falls. From a biological standpoint, it seems unreasonable to assume that juvenile brown trout can successfully follow the water up and down the bank over changes in stage of nearly 20 ft that occur in some parts of the Cumberland River. Food availability is probably limited for juvenile brown trout, since the riverbanks will be exposed for part of the generation cycle. Fluctuation zones of rivers below peaking projects are generally devoid of benthic macroinvertebrates that have food value for fish. Based on these considerations, the amount of habitat for juvenile brown trout, particularly in the most upstream and middle river reach, is probably less than indicated by this analysis and may even be negligible.

Adult rainbow trout

62. In general, habitat for rainbow trout adults tracks that of adult brown trout near Wolf Creek Dam, being 10 to 20 percent lower during low and high flow and about equal during the rising and falling arms of the peaking hydrograph. Habitat for rainbow trout is reduced compared to brown trout habitat in the river reach near the dam because backwater effects result in near-zero water velocities (rainbow trout habitat suitability declines to near zero as velocities approach 0.0 fps).

63. The middle and lower reaches of the river provide a greater amount of habitat for adult rainbow trout than for brown trout during the falling arm of the peaking hydrograph since water velocities are always substantially

above 0.0 fps. Rainbow trout habitat decreases during low-flow periods until the amount of habitat declines to a value less than that for brown trout.

64. Minimum (potential refugia) habitat values track those of brown trout near the dam and are of approximately the same value. However, except under 10-percent exceedance conditions, minimum values of rainbow trout habitat exceed brown trout habitat values at most transects downstream of RM 442. Again, this is related to the constant availability of water velocities above zero in the two most downstream reaches.

Uprate Release Schedules

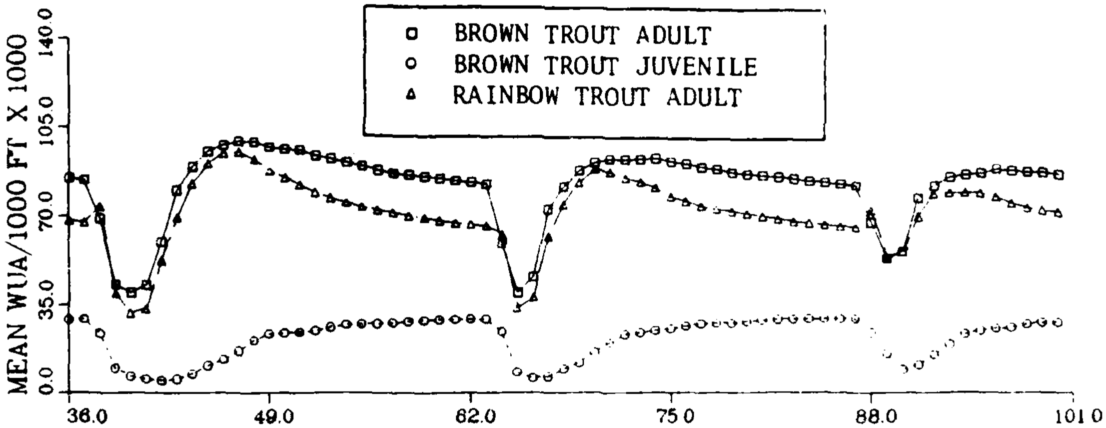
General results

65. Under dry conditions (September), uprate scenarios appear to have little or no effect upon available habitat for the three life stages. During the hours when changes were noticed, the loss of habitat under uprate conditions was less than 5 percent from levels under existing conditions (Figures 7-9). However, under average (50-percent exceedance) release patterns, substantial losses of habitat are predicted under peaking conditions. This pattern of habitat loss is repeated under high-flow patterns (10-percent exceedance) and is most notable in cross sections downstream of RM 449.4. Minimum habitat availability (minima occurred during peaking operation) also declined under all hydrologic scenarios (Figures 10-12).

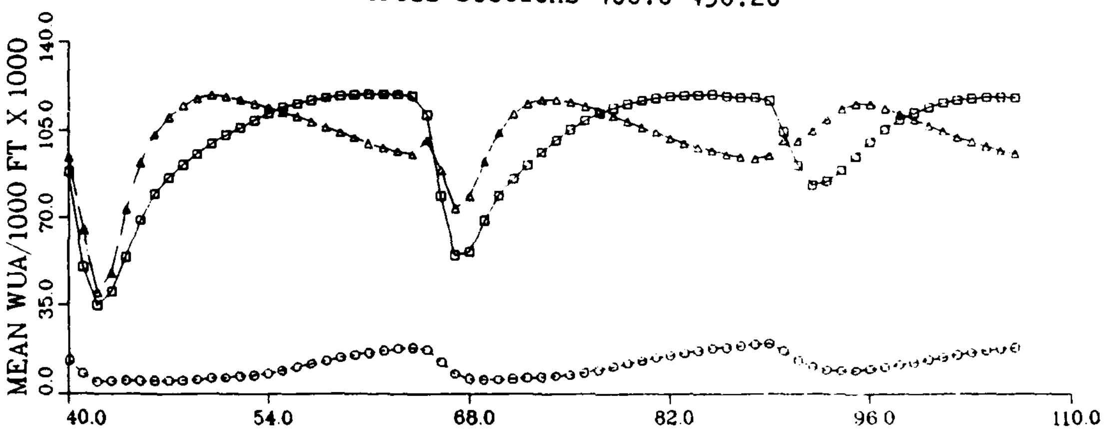
Brown trout adults

66. Virtually no changes in available habitat are predicted under dry (September) conditions near Wolf Creek Dam. However, the duration of the habitat minimum increases slightly as the peaking wave moves downstream to the two more downstream reaches. The higher discharge level results in an increase in the duration of the falling arm of the hydrograph and, as a result, the period of minimum habitat value is extended (the habitat minimum extends throughout the generation wave and into the first half of the falling arm of the hydrograph). For example, in group 2 cross sections (Figure 8), the habitat minimum during Saturday generation is extended by about 1 hr under uprate conditions compared with existing conditions (Figures 1 and 7).

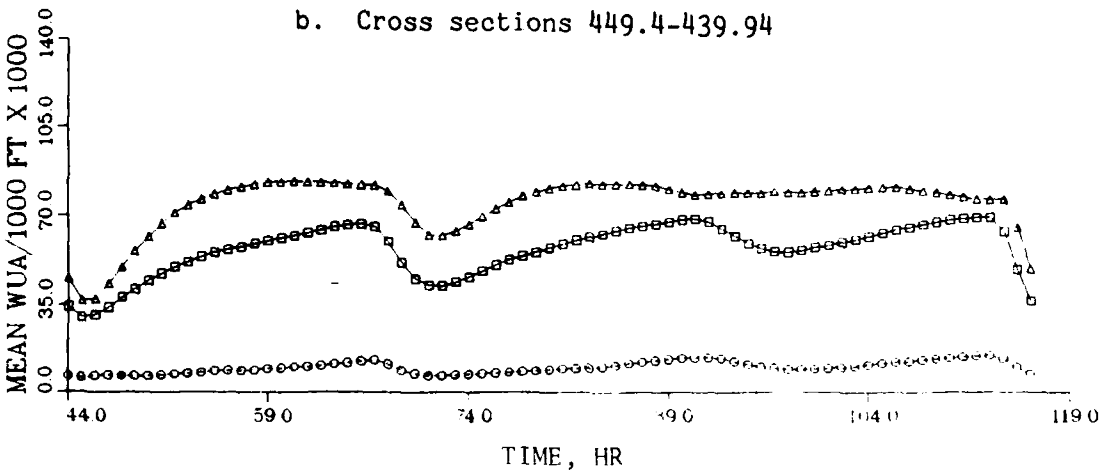
67. Under average hydrologic conditions, minimum habitat for brown trout is reduced in the reach immediately downstream of Wolf Creek Dam. At the upstream cross sections (RM 460-450.26), there is a 6-percent loss of



a. Cross sections 460.0-450.26

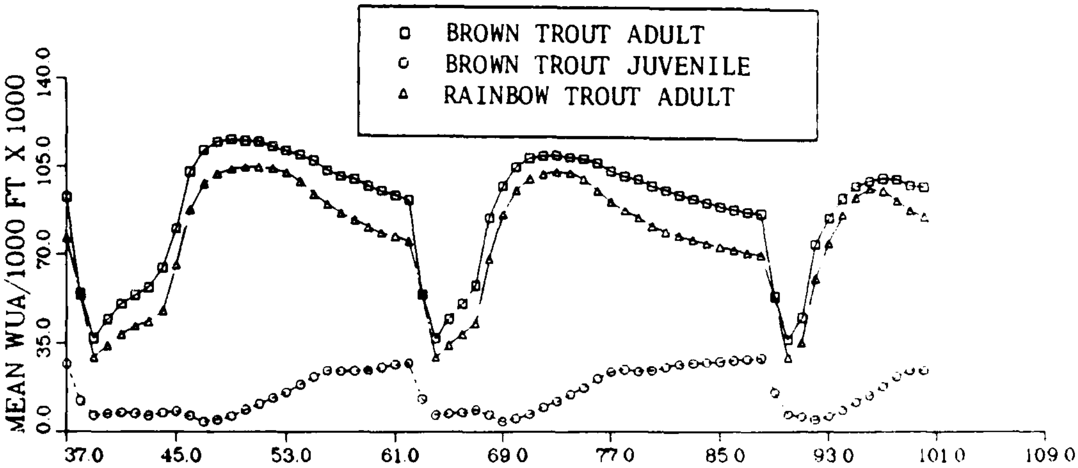


b. Cross sections 449.4-439.94

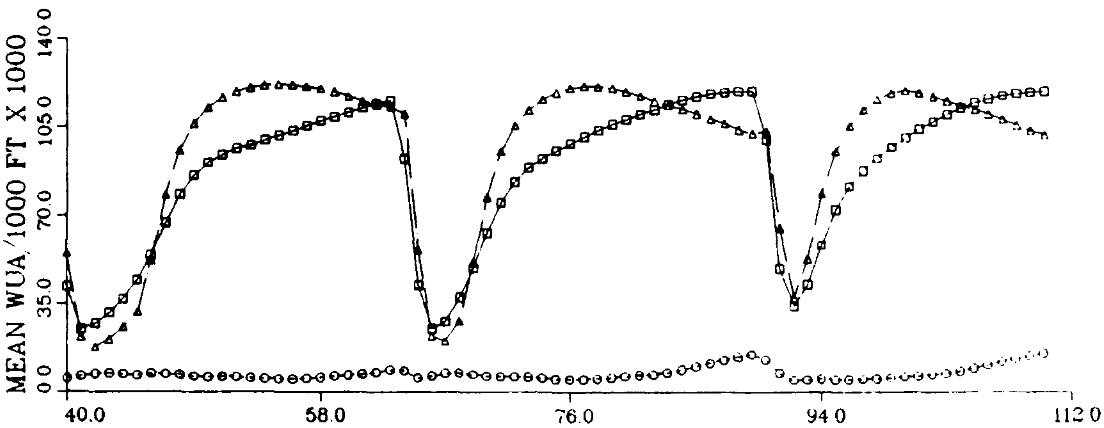


c. Cross sections 438.88-427.80

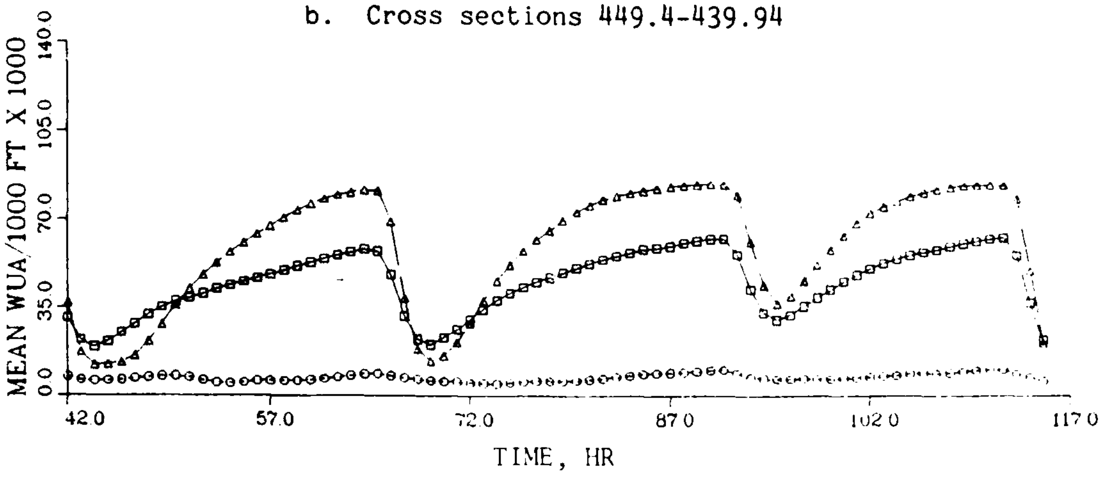
Figure 7. Mean habitat available during weekday and weekend release schedules, September uprate conditions



a. Cross sections 460.0-450.26

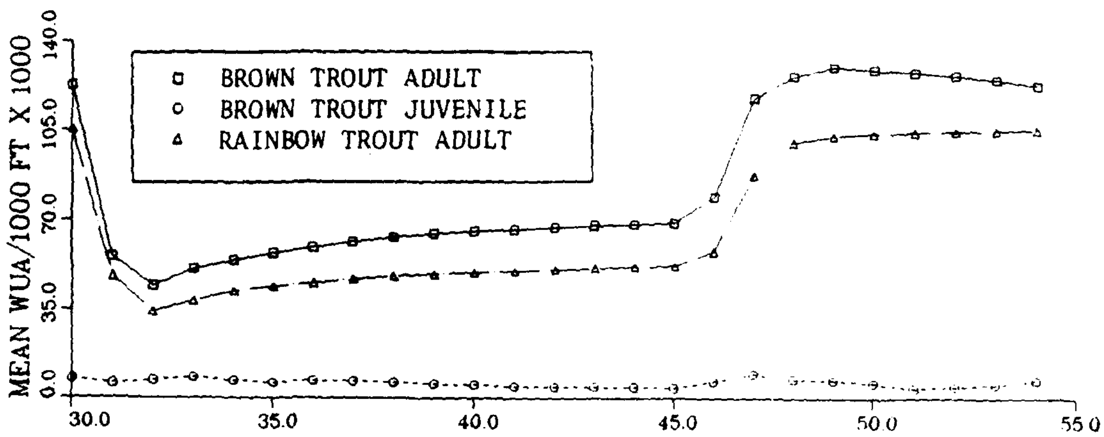


b. Cross sections 449.4-439.94

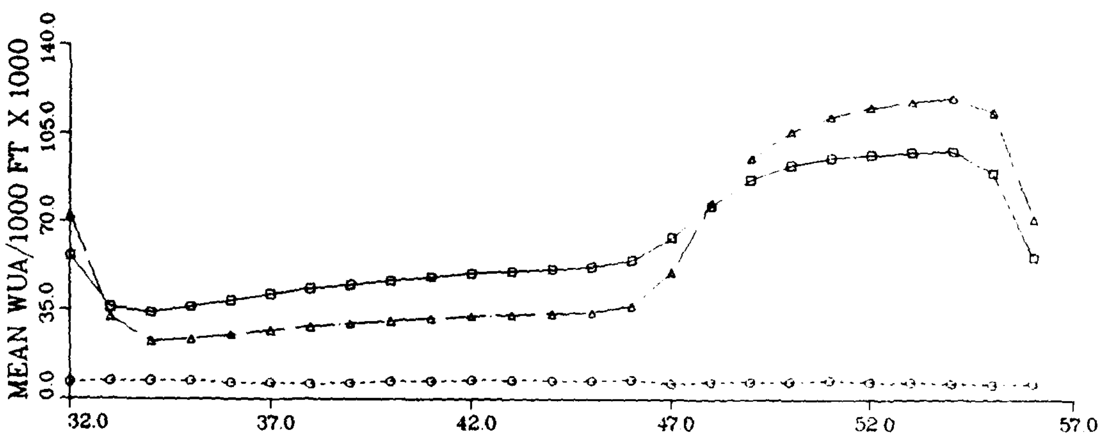


c. Cross sections 438.88-427.80

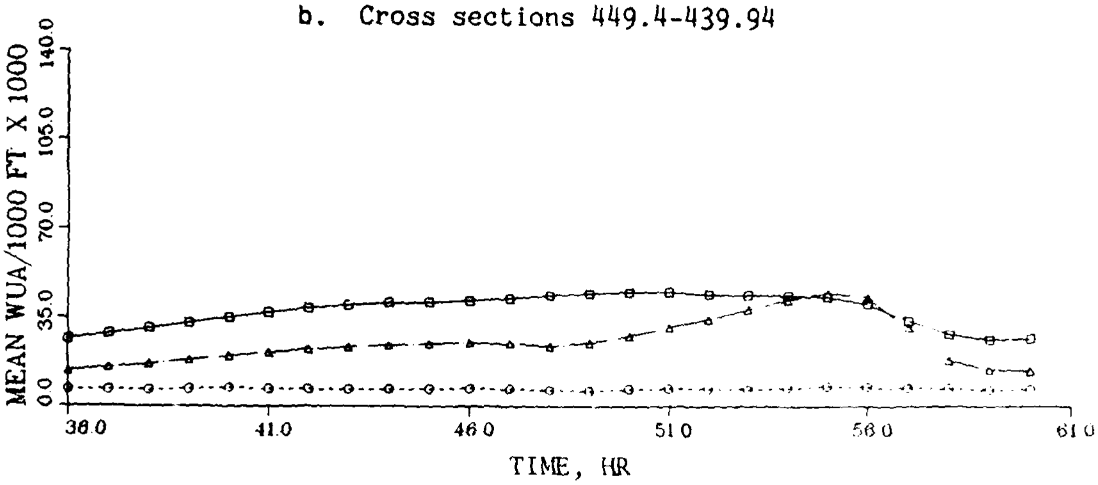
Figure 8. Mean habitat available during weekday and weekend release schedules, 50-percent uprate conditions



a. *Cross sections 460.0-450.26*

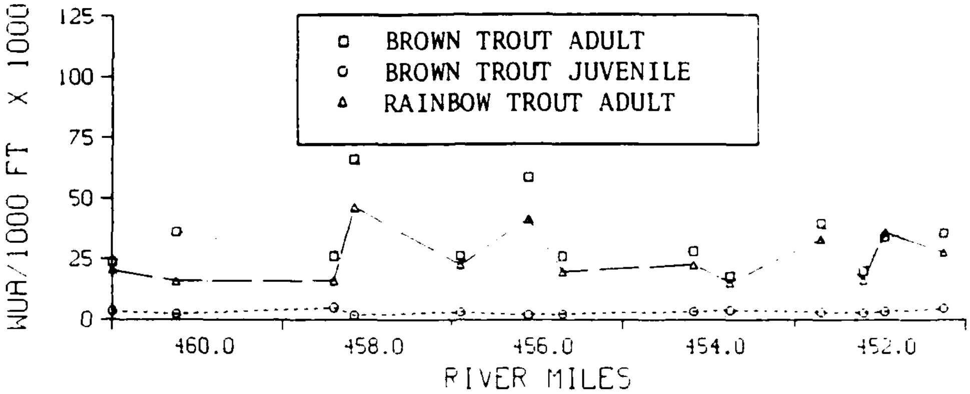


b. Cross sections 449.4-439.94

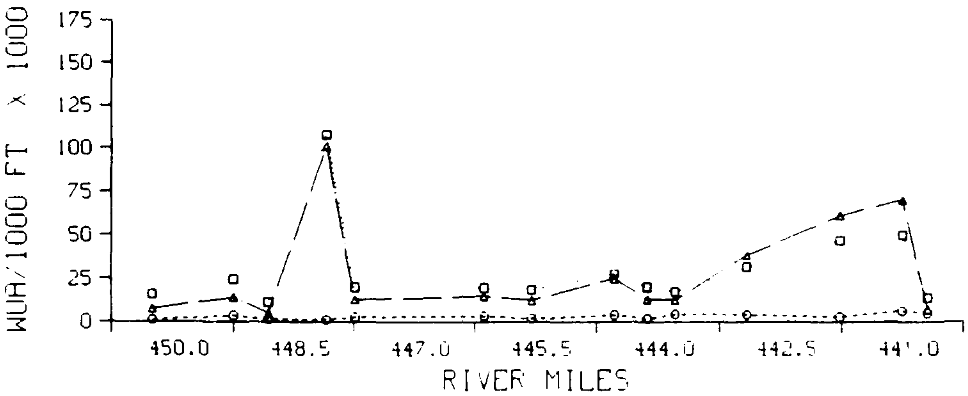


c. Cross sections 438.88-427.80

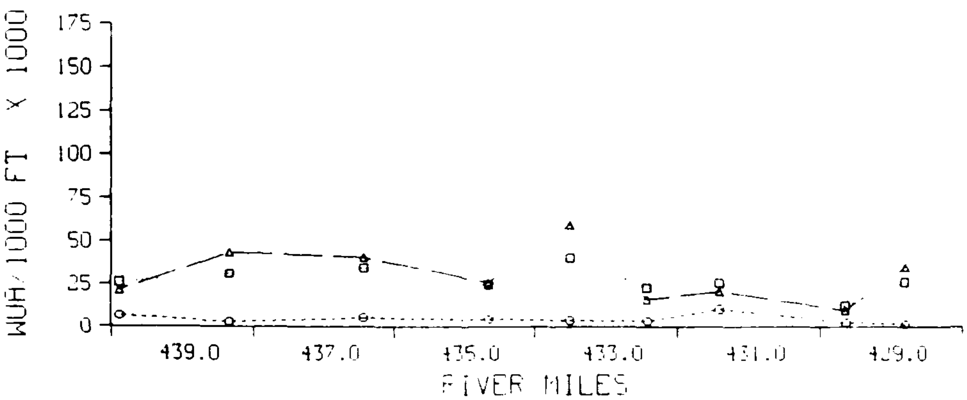
Figure 9. Mean habitat available during weekday and weekend release schedules (identical for all days), 10-percent uprate conditions



a. Group 1 - simulated hours 36-100

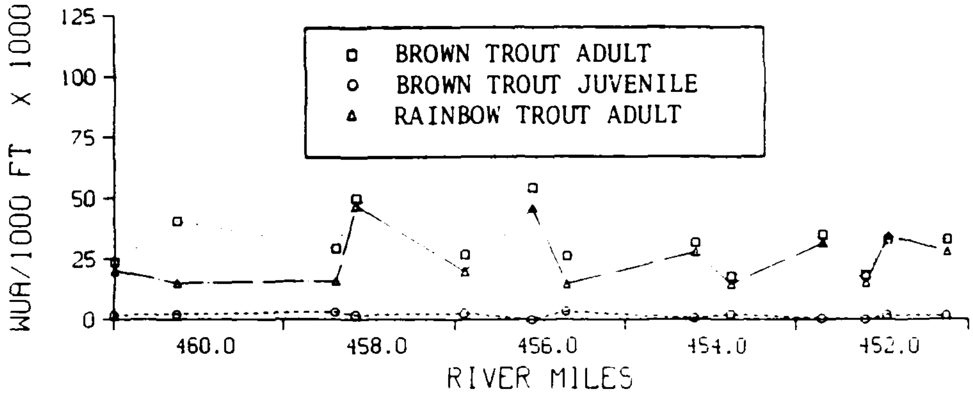


b. Group 2 - simulated hours 40-106

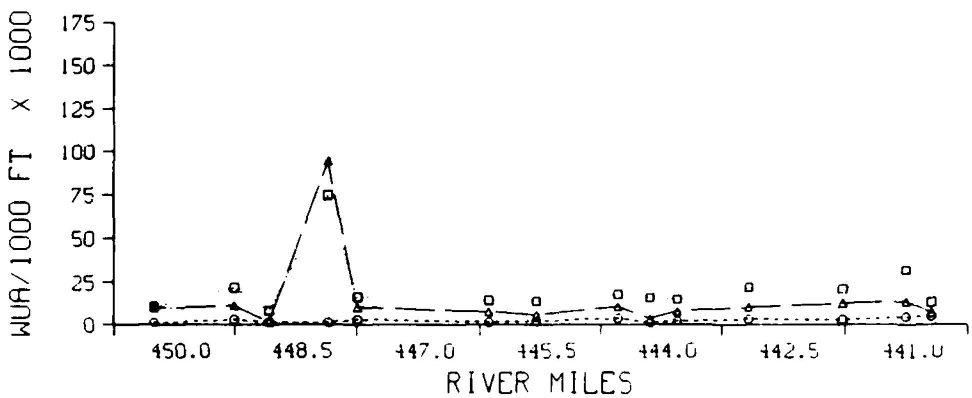


c. Group 3 - simulated hours 44-116

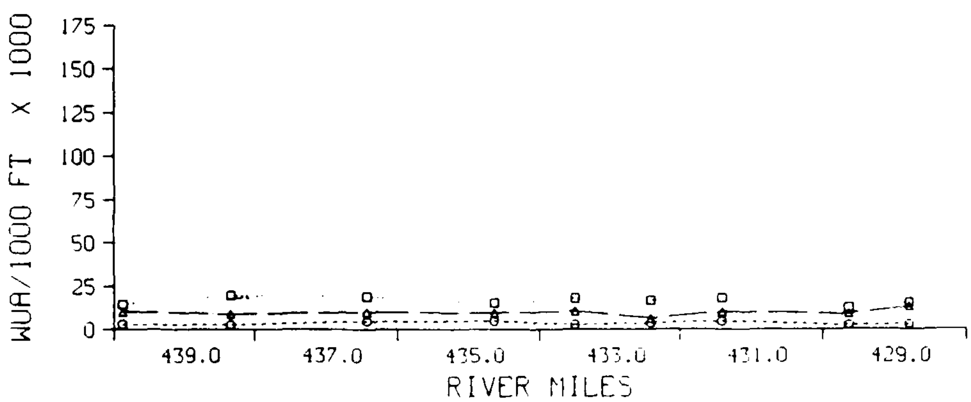
Figure 10. Minimum habitat available at each cross section, September uprate conditions



a. Group 1 - simulated hours 37-100

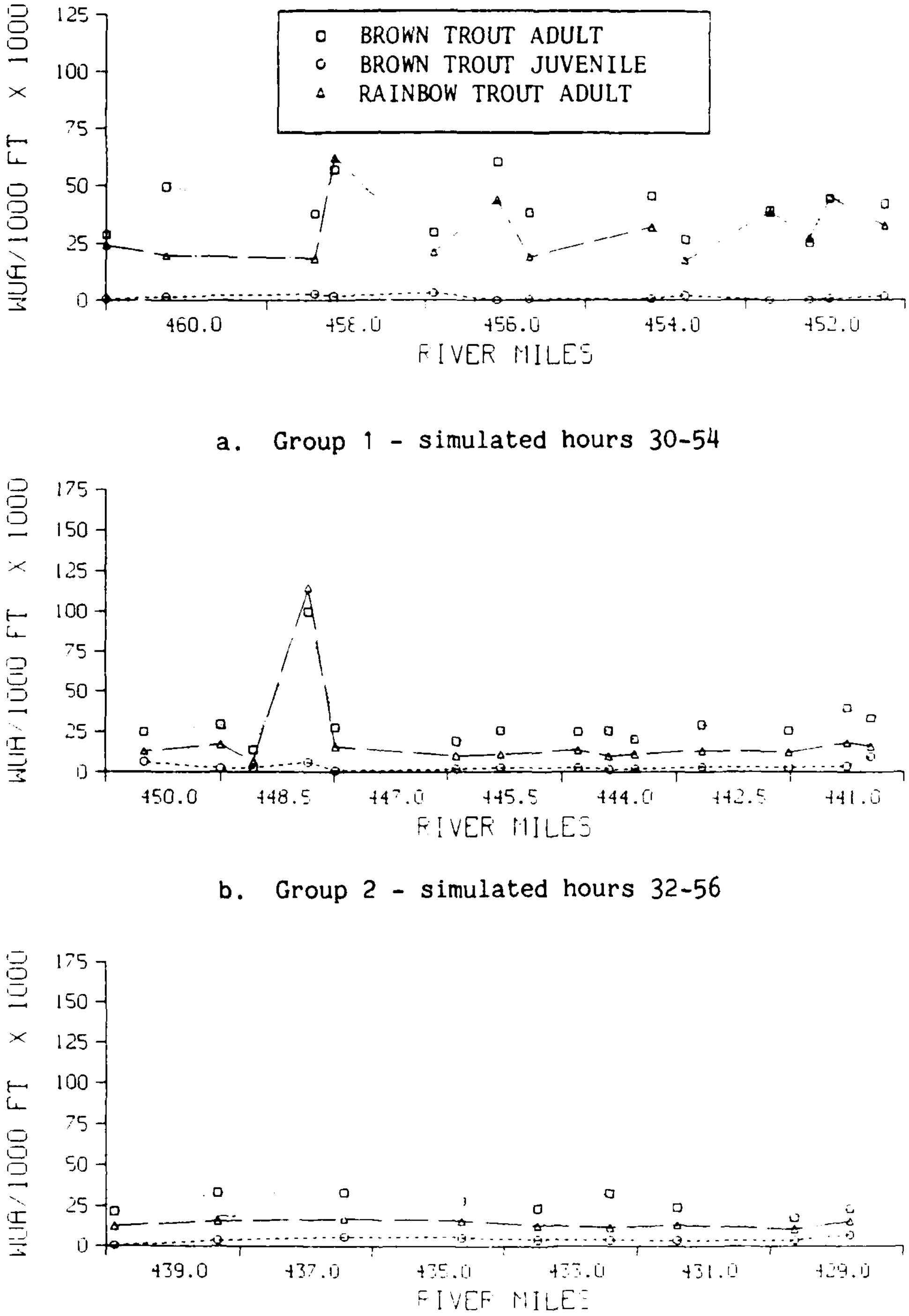


b. Group 2 - simulated hours 40-110



c. Group 3 - simulated hours 42-115

Figure 11. Minimum habitat available at each cross section, 50-percent uprate conditions



a. Group 1 - simulated hours 30-54

b. Group 2 - simulated hours 32-56

c. Group 3 - simulated hours 36-60

Figure 12. Minimum habitat available at each cross section, 10-percent uprate conditions

habitat under uprate conditions compared with existing conditions (see Table E6, Appendix E). This trend continues downstream with 10- to 15-percent greater habitat losses under uprate conditions at the middle cross sections and comparable losses in the most downstream reach (Tables E7 and E8). Maximum habitat (during nongeneration, low flows, and toward the low-flow side of the descending arm of the peaking hydrograph) is approximately the same for uprate conditions as for existing conditions (Figures 2 and 8).

68. Under potential flood conditions (10-percent exceedance), habitat loss at the most upstream reach is approximately 20 percent during the first few hours of generation (Table E3). However, the duration of the uprate generating cycle under the 10-percent hydrologic condition is shorter than the existing cycle, so the minimum habitat periods were shorter (Figures 3 and 9). Habitat area returns to levels comparable to existing hydrologic conditions during the falling arm of the hydrograph.

69. In the middle reaches there is a 30-percent habitat loss during the peaking period compared with existing hydrologic conditions (Table E4). However, because the duration of the generation period is shorter, the duration of the habitat minimum is also shorter. In the most downstream reach, attenuation of the generation surge produced only a 22-percent greater habitat loss under the 10-percent uprate conditions (Table E5). However, it should be noted that this loss is for a short period of time (1 hr) and that available habitat under existing conditions with 10-percent exceedance is low.

Brown trout juveniles

70. Uprate release schedules generally result in declines in habitat for both adult life stages under all hydrologic conditions. However, habitat predictions for juvenile brown trout are less consistent than predictions for the two adult life stages. Under dry (September) conditions, uprate release schedules result in minimal changes in predicted habitat for juvenile brown trout (Tables E9-E11). Under average (50-percent exceedance) hydrologic conditions, little habitat is available for juveniles under existing conditions, and uprate conditions are not predicted to decrease these amounts (Tables E6-E8). Predicted habitat under potential flood release schedules (10-percent exceedance) declines by 50 percent from existing release schedules near the dam but does not significantly reduce habitat at cross sections farther downstream.

71. Uprate release schedules do not result in substantial changes in

minimum habitat for juvenile brown trout. In most cases, the depths required by juvenile brown trout are less than the predicted changes in stage from existing to uprate releases. However, at those few transects that are broad and shallow (for example RM 455.1), the uprate schedule results in total loss of juvenile brown trout habitat. Depth or velocity tolerances are exceeded in the channel, and the flooded riparian zone provides negligible habitat for this life stage.

72. In general, habitat value for juvenile brown trout is so low under both existing and uprate conditions that definitive statements about habitat loss or gain are tenuous. Most habitat for juveniles is probably located in the fluctuation zone at the river edges, and the small values predicted are probably substantially less than the uncertainty in the analysis.

Rainbow trout adults

73. In general, predicted habitat for rainbow trout adults under uprate release schedules is similar to trends predicted for adult brown trout habitat. Loss of habitat for both life stages results from increased discharge rates under uprate release schedules. Under dry (September) conditions, a 10-percent loss of habitat is observed for the middle and lower reaches during peaking discharges compared with the existing schedule (Tables E10 and E11). Under 50-percent (average) hydrologic conditions, the loss of rainbow trout habitat at peak discharges is increased by 31 percent at the middle reaches (Rock House) and by 18 percent at the most downstream areas (Tables E7 and E8). However, habitat values increase during low-flow periods for rainbow trout because the duration of the nongeneration period increases under uprate release schedules as compared with existing 10-percent release schedules (Figures 3 and 9).

PART IV: DISCUSSION

74. A general examination of discharge patterns relative to trout habitat requirements indicates violation of both depth criteria (too shallow during nongeneration or low flows) and velocity criteria (too high during generation) for the various life stages during the generation cycle.

Life Stage Differences

75. General results for the three life stages evaluated are primarily determined by the range of depths and velocities that each can tolerate as indicated by suitability criteria (Appendix A). Adult brown trout have the greatest range of tolerance for both depth and velocity. Thus, adult brown trout generally have the most habitat available under existing and uprate conditions. However, adult rainbow trout have more predicted habitat during dry and average hydrologic conditions in the middle and most downstream reaches. Dampened stage and velocity changes resulting from attenuation of the power wave as it moves downstream and the presence of broad, shallow cross sections result in hydraulic conditions that more nearly meet the habitat requirements of adult rainbow trout. This life stage has narrower velocity tolerances but can tolerate shallower water than adult brown trout.

76. Juvenile brown trout have the least habitat under both existing and uprate release schedules because they have the narrowest criteria for both depth and velocity. The results of this analysis indicate that juvenile brown trout habitat is restricted to narrow bands along the edges of the river. Consequently, temporal and spatial patterns in juvenile brown trout habitat are not discernible except during September hydrologic conditions. Probably, the amount of habitat available for juvenile brown trout is negligible under both existing and uprate release schedules.

77. Fish habitat predictions under dynamic flow conditions are difficult to summarize because of the complex flow conditions in the river and because other case history studies are unavailable for comparison. In addition, very little information is available regarding the response of fish to peaking releases. Thus, the manner in which habitat values should be summarized to best relate changes in flow conditions to impacts on fish is not completely known. Adult brown trout and adult rainbow trout habitat information

is probably best represented as habitat summaries over time for each cross section. However, to be on the conservative side, this report generally discusses impacts of uprate in terms of minimum habitat. Adults are strong swimmers and have relatively broad habitat requirements and could probably relocate to avoid local habitat losses during peaking releases. The distances that adults would likely travel remains to be investigated and remains a critical concern in this assumption.

78. Juvenile brown trout, on the other hand, have narrow habitat requirements and do not have the swimming ability of adults. Therefore, the effects of different flow conditions are probably best represented as the minimum habitat available for each cross section during the generation cycles. In the cases where no habitat is available under certain operational scenarios, this probably represents a loss of juvenile brown trout from that area.

79. Minimum habitat values for adults of brown and rainbow trout are probably not as critical due to adult mobility but do represent valid biological concerns. In the event that adults do not respond to peaking releases by moving relatively large distances longitudinally, the availability of adequate habitat refugia at each cross section is an important factor to consider for a complete assessment of different release scenarios. In this case, the minimum habitat available for adults during the generation cycle must be examined. Biological information on the "packing" or refuge value of these habitat areas under peaking operation is not currently available. However, it is likely that the duration of periods of minimum habitat will be important to the maintenance of adult brown and rainbow trout. That is, fish stress is more likely to occur as the duration of habitat minima increases.

Temporal and Spatial Distribution of Habitat

80. Operations at Wolf Creek Dam can be broadly categorized as generation and nongeneration. During generation, flows increase suddenly, remain high for up to several hours, and then decline to a base flow. Under both existing and uprate release schedules, generating flows have the greatest impact on trout habitat downstream of the dam because high velocities associated with peak discharges exceed the tolerance limits for the life stages/species studied. The duration of the peak release generally determines the length of time that habitat minima occur at each cross section.

81. Habitat for adult brown trout and adult rainbow trout varies longitudinally under existing and uprate conditions. Differences in habitat result from longitudinal changes in both cover and substrate. Downstream (RM 455 and lower) channel morphology and substrate have less fractured bedrock, boulders, and cobble, which translates into decreasing cover with distance from the dam. However, flow conditions also change with increasing distance from Wolf Creek Dam. Maximum discharge decreases downstream as the power wave attenuates, with an associated increase in the low flow. Thus, the high velocities that limit trout habitat during generation are reduced as the peak release flows downstream. In the case of rainbow trout, the increase in low flows combined with wider and shallower cross sections farther downstream results in more adult rainbow trout than adult brown trout habitat available during the driest hydrologic periods.

Effects of Uprate

82. The predicted responses of adult brown trout and adult rainbow trout are sufficiently similar that both can be discussed together. Less habitat is consistently available for both species under uprate release schedules than under existing release schedules. The following discussion concentrates on habitat comparisons between existing and uprate release schedules under average (50-percent exceedance) hydrologic conditions. The same general trends hold true for other hydrologic conditions, except where noted.

83. Habitat loss under uprate conditions results primarily from:

a. Velocity increases associated with increased discharges (discharge increases by 9,600 cfs during both weekend and weekday releases).

b. An increase in the duration of that portion of the falling arm of the hydrograph that exceeds the velocity tolerance of the two adult life stages. The rate of change of water surface elevation under uprate conditions is increased during the rising arm of the generation cycle and decreased during the postgeneration period.

84. The most noticeable exception to the general decrease in predicted habitat under uprate release schedules noted in the preceding paragraph occurs under 10-percent exceedance conditions. Under uprate release schedules, the duration of the peaking wave is decreased by approximately 6 hr from existing 10-percent hydrologic conditions. Reduced duration of peaking discharges

results in increased duration of nongeneration (base flow) conditions. Increasing the duration of the nongeneration period increases predicted habitat during nongeneration periods (Figures 3 and 9) and total habitat during the entire generation cycle (Appendix E). During nongeneration, depths and velocities in the river are more likely to fall within the tolerances of the two adult life stages.

Other Considerations

85. Comparison between existing and uprate release schedules for hydropower operation at Wolf Creek Dam involves factors other than changes in available habitat. These additional factors include, but are not limited to, differences in water quality, effects on benthos (fish food), and changes in shape or substrate composition of the river channel. Changes in physical habitat, such as channel aggradation and degradation and bank sloughing, fall outside the purview of this study and may require further study.

86. Although water quality conditions in the study reach may differ between existing and uprate conditions, the differences are probably not significant since travel time of water through the river reaches studied is similar for both conditions (Martin, Curtis, and Nestler 1985).

87. The benthic community may be affected by uprate release schedules for several reasons. First, benthic biomass and diversity of some species, particularly taxa such as mayflies, stoneflies, and caddisflies which often represent major diet items of fish, are reduced in the fluctuation zone in the tailwaters of peaking hydropower projects (Ward and Stanford 1979). Uprate release schedules will result in an increase in the size of the fluctuation zone because maximum discharge rates will increase compared with existing release schedules, whereas minimum releases will remain the same. The effects of increasing the size of the fluctuation zone will be more pronounced near the dam before the peaking wave begins to attenuate. The effects of increasing the size of the fluctuation zone are compounded by thermal effects from hypolimnetic withdrawal, which are known to generally reduce successful completion of life cycles of resident benthic populations (Ward and Stanford 1979).

88. Uprate release schedules may produce hydraulic conditions (increased maximum discharge) that result in an increase in benthic drift.

Statzner (1981) and Statzner and Higler (1986) have demonstrated that shear stresses along the substrate are the most likely determinants of distribution of most benthic species along the length of a stream. As shear stresses (Reynolds' number) increase, benthic invertebrates are less able to forage across surfaces of cobbled substrates. In response, benthic organisms abandon unsuitable stream reaches by entering the drift until the impacted reach may be largely devoid of benthos. Gore (1977) and Bovee, Gore, and Silverman (1978) have demonstrated that a threshold discharge must be passed to initiate drift events. Although threshold discharges can be predicted using IFIM techniques, considerable investigation time must be spent to determine habitat criteria for benthic species. These criteria are currently unavailable for the Cumberland River.

89. Partial amelioration of the effects of uprate release schedules may be possible by reducing or avoiding night (sunset to sunrise) releases when the majority of benthic species are foraging (Waters 1972). However, a complete assessment of the feasibility of implementing operational guidelines to reduce effects of uprate is predicated on the use of more detailed information on the responses of benthos to discharge than is currently available. Additionally, the ameliorative effects of operational guidelines will be restricted to a single reach of river because of the 8-hr travel time of the peaking wave through the system. Consequently, it will not be possible to formulate a set of guidelines that produce the desired nighttime flow conditions simultaneously in the three river reaches. However, avoiding or reducing peaking discharges during nighttime may be of value for the most upstream reach where the flow effects of uprate are most pronounced.

Study Limitations

90. This study, like any study that predicts the effects of future changes in operation or condition, is limited both by inherent shortcomings in the quantitative methods used and by assumptions made in the analysis. A partial list of study limitations is included below:

a. Predictions of trout habitat made in this report are made relative to habitat criteria developed and projected from measurements taken at 0.6 × depth of the sample. Trout can be found at a wide variety of depths. In pool situations, most are found at greater depths than standard criteria would predict.

b. Detrimental effects of peaking operation are probably overestimated. Boulders, rock shelves, and other river features that provide refuge from high flow are common in the Cumberland River, particularly in the most upstream reach.

c. Habitat is assumed to change instantly with flow in this study. In fact, the ability to predict physical habitat under dynamic flow conditions probably exceeds an understanding of how fish react during a generation cycle. Thus, for this reason as well as those explained in a and b, results in this report are relative in nature rather than absolute. However, the results are adequate for making relative comparisons between operation scenarios.

d. The suitability curves used in this study were obtained from a previous study and were assumed to apply for the Cumberland River trout fishery. Although use of the suitability curves was considered defensible, the validity of the suitability curves was not tested.

e. Cross sections used as a basis for predicting trout habitat under different alternatives were originally selected for the purposes of developing elevation-capacity information and providing data for hydraulic simulation. This study assumes that no critical areas were omitted and that these cross sections are adequate for representing trout habitat in the Cumberland River.

PART V: CONCLUSIONS AND RECOMMENDATIONS

91. Results of this study lead to the following conclusions:

- a. More adult brown trout and adult rainbow trout habitat (including minimum, average, and maximum habitat) is available under existing release schedules for both dry (September) and average hydrologic conditions (50-percent exceedance) than for uprate release schedules. However, greater habitat, both as total and average habitat, is available under uprate release schedules for 10-percent exceedance conditions because of reduced generation time compared with existing release schedules under 10-percent exceedance flows.
- b. Changes in juvenile brown trout habitat followed the same general trends as those of adults in that predicted habitat declined during peaking generation and increased at low flows. However, comparisons between existing and uprate release schedules yielded no consistent patterns. Predicted juvenile habitat was negligible at a number of the cross sections in the middle reach.
- c. Changes in habitat availability between existing and uprate conditions were determined by the rate of discharge (as discharge increases predicted habitat availability declines) and duration of the generation cycle (increased discharge duration shortens the time period of maximum predicted habitat and also results in declines in minimum (refuge) habitat available by increasing the duration of the falling arm of the daily hydrograph).
- d. Trout habitat within the study reach is highly dependent upon daily operational schedules at Wolf Creek Dam for both sets of release schedules. The conclusions of this study are based on release scenarios provided by ORN for Wolf Creek Dam operation under various hydrologic conditions. Other release scenarios may generate different results depending upon details of operation.

92. If operationally feasible, it is recommended that development of release guidelines be considered for minimizing downstream impacts of hydropower uprate. For example, restricting night generation may minimize the effects of uprate on benthic macroinvertebrates in the most upstream river reach.

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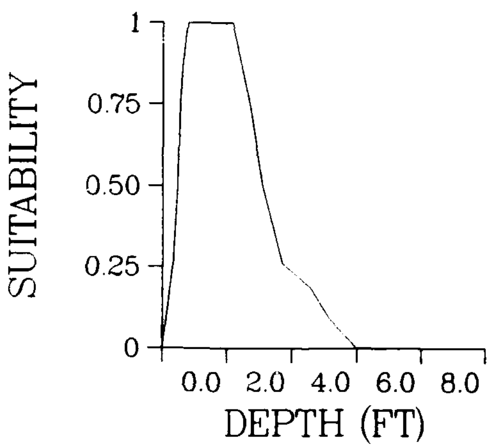
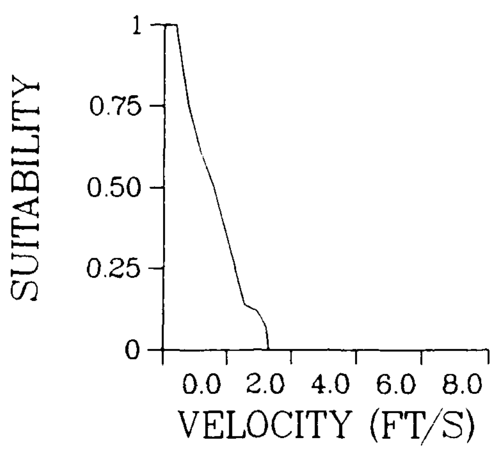
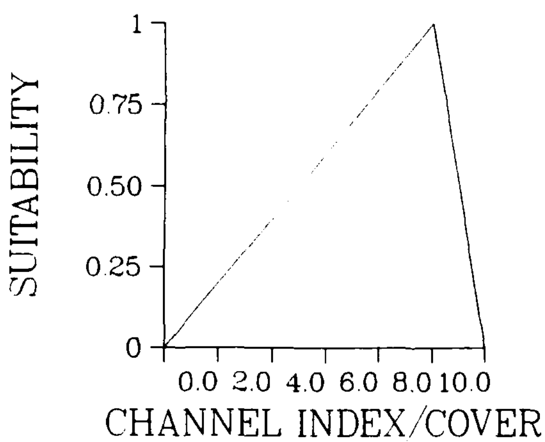
APPENDIX A: SUITABILITY CURVES FOR TROUT LIFE STAGES

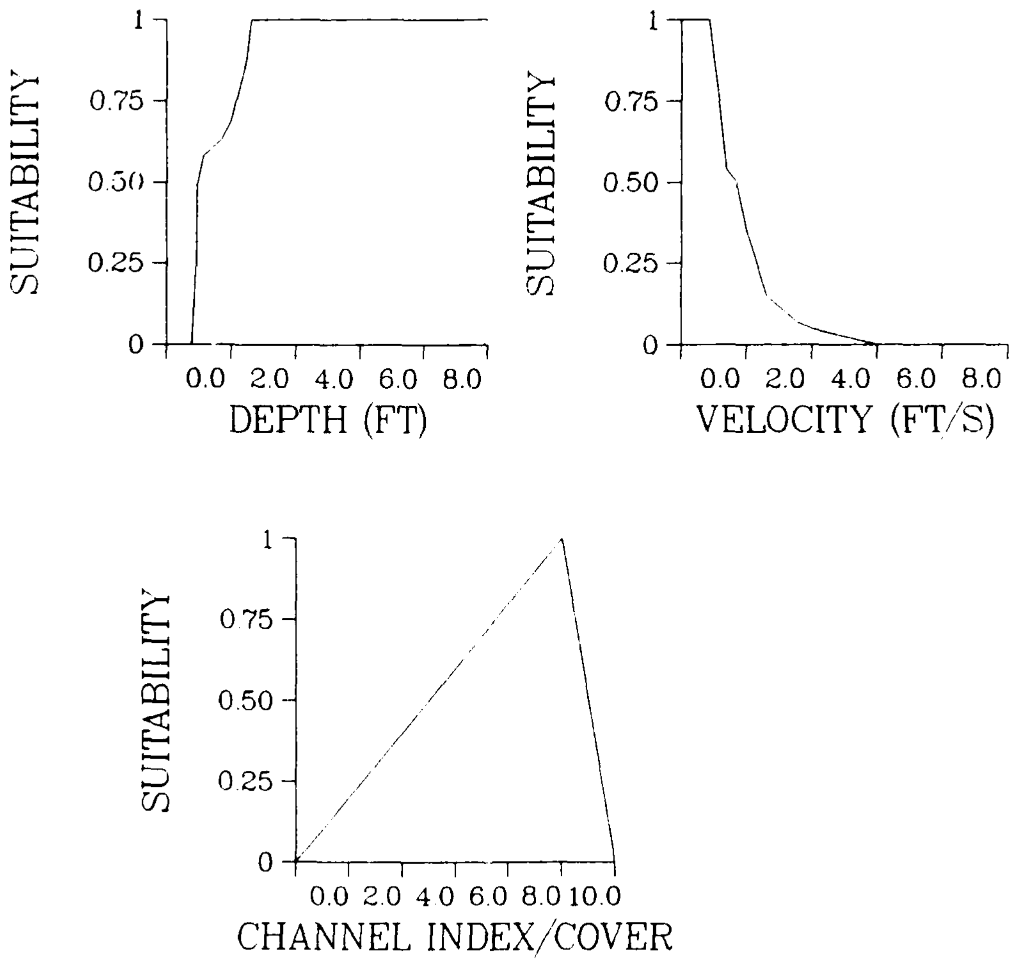
BROWN TROUT – JUVENILE



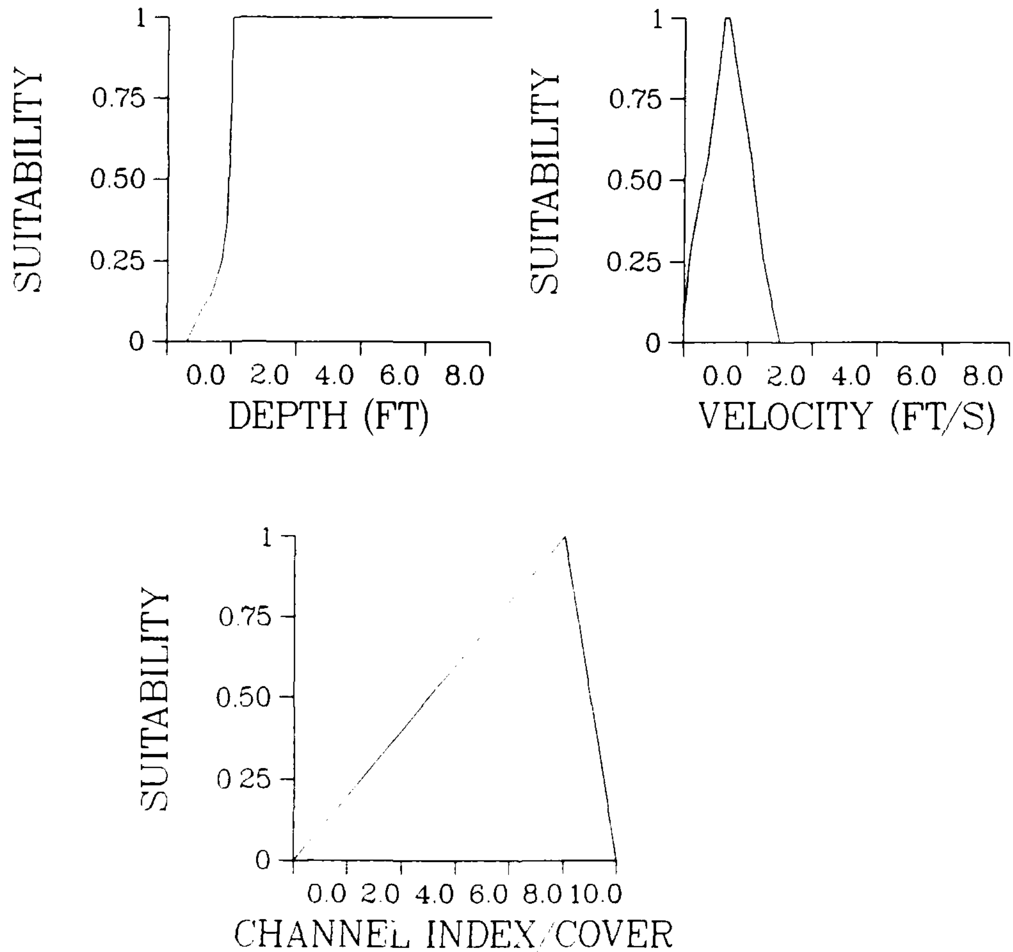




BROWN TROUT - ADULT



RAINBOW TROUT - ADULT



APPENDIX B: DISCHARGE AND STAGE RELATIONSHIPS FOR EXISTING AND UPRATE SCENARIOS AT RIVER MILES REPRESENTING SIMULATION GROUPS

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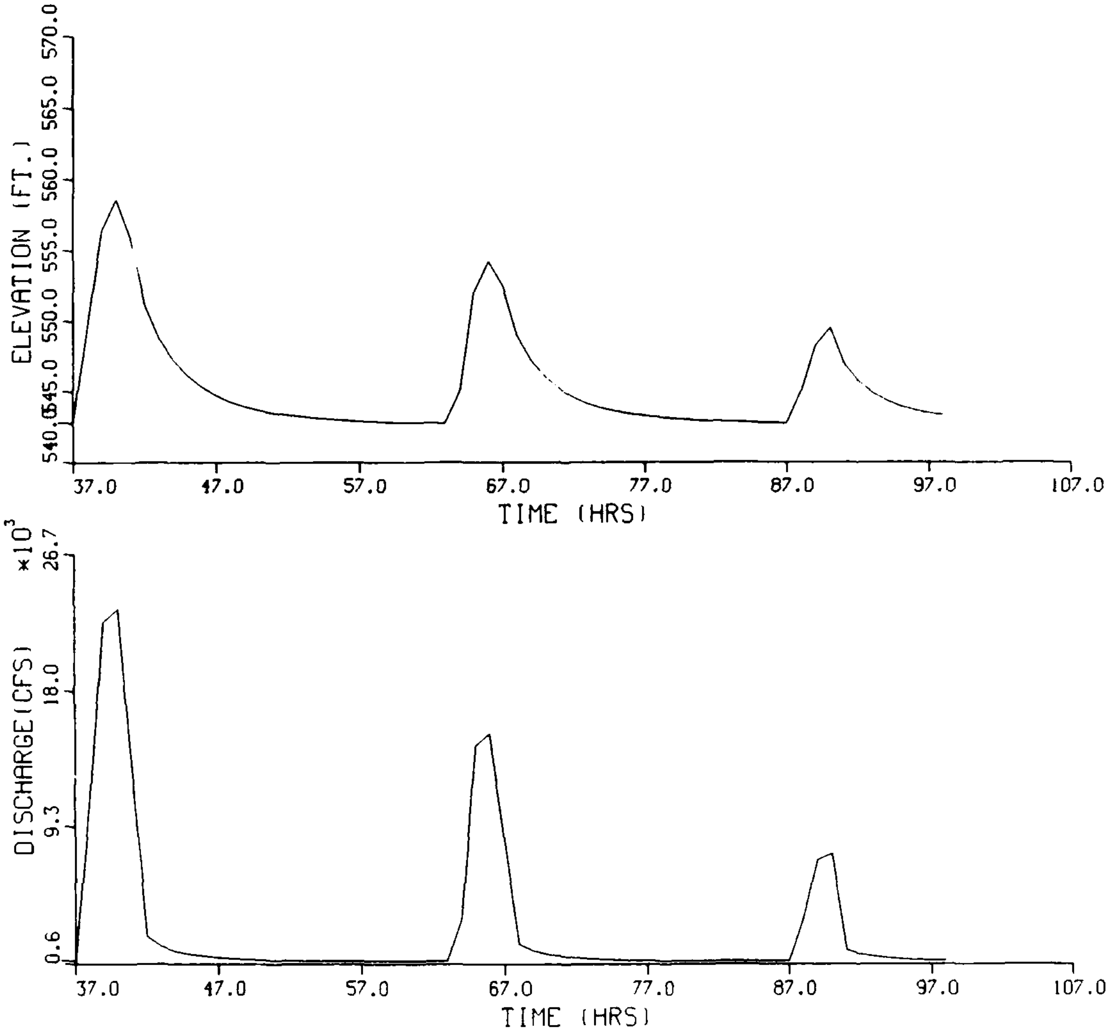

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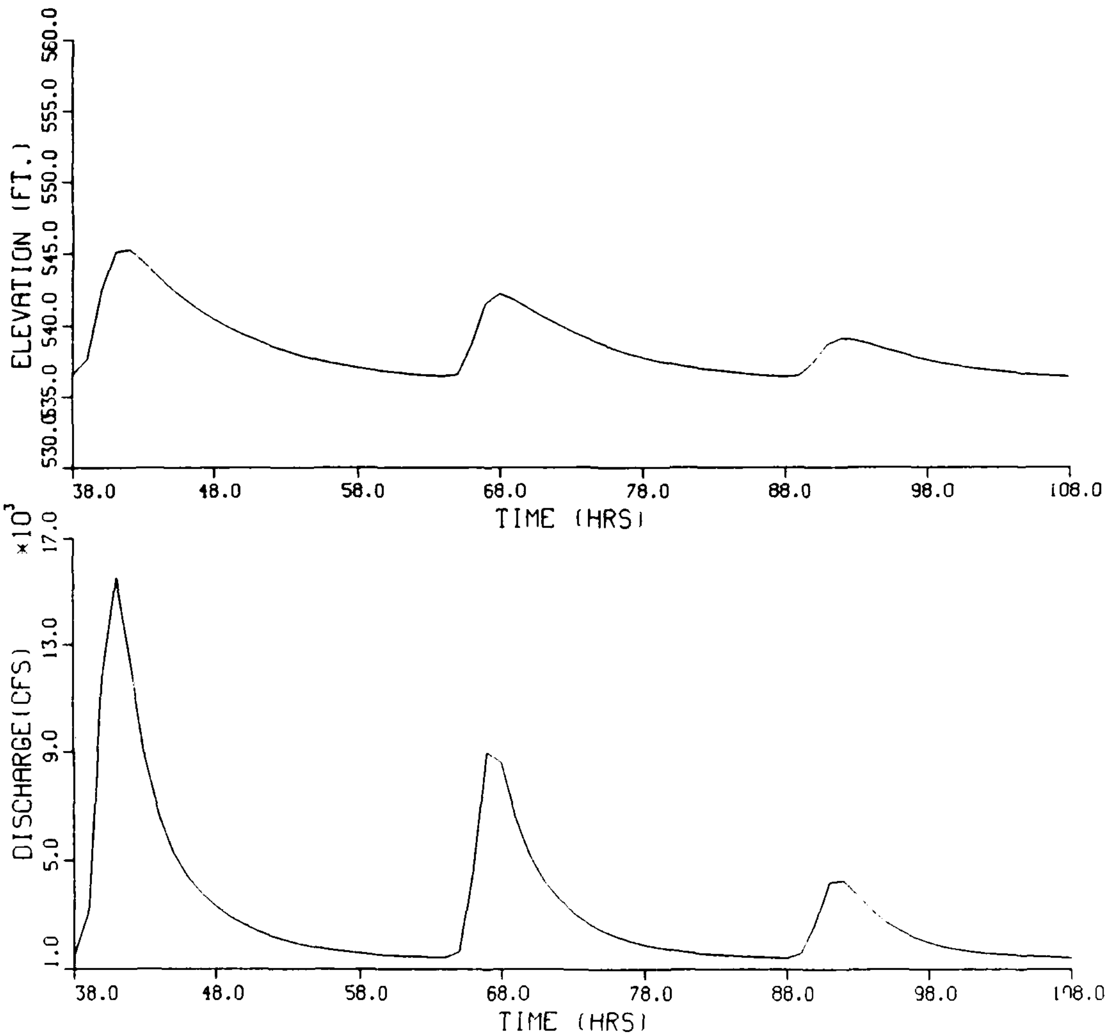

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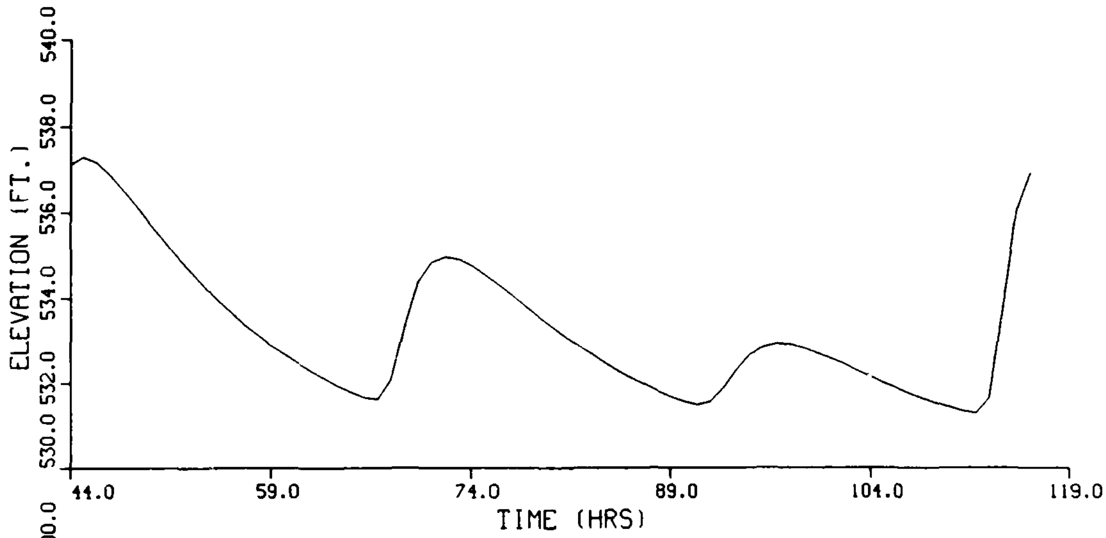

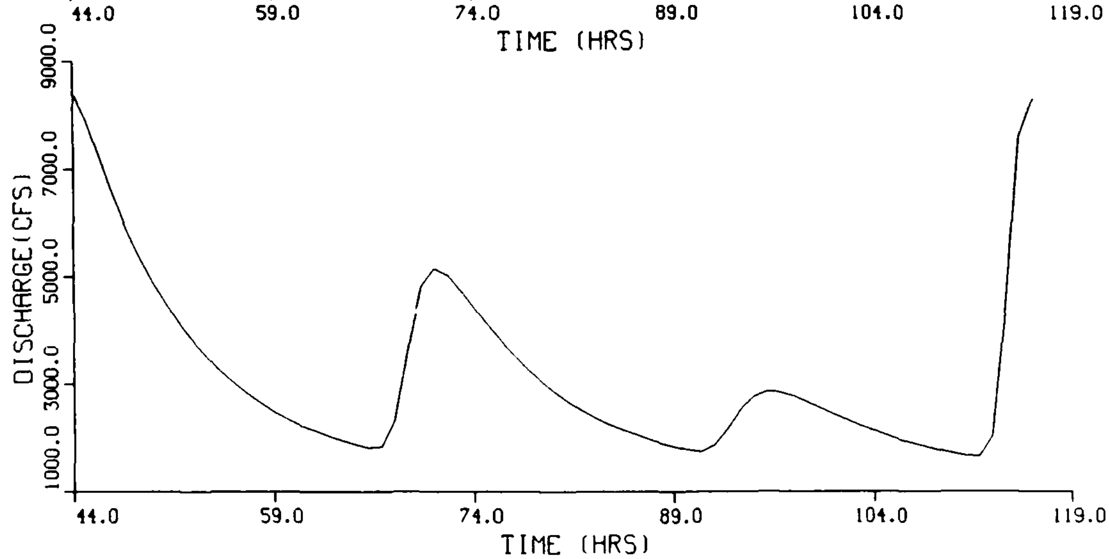

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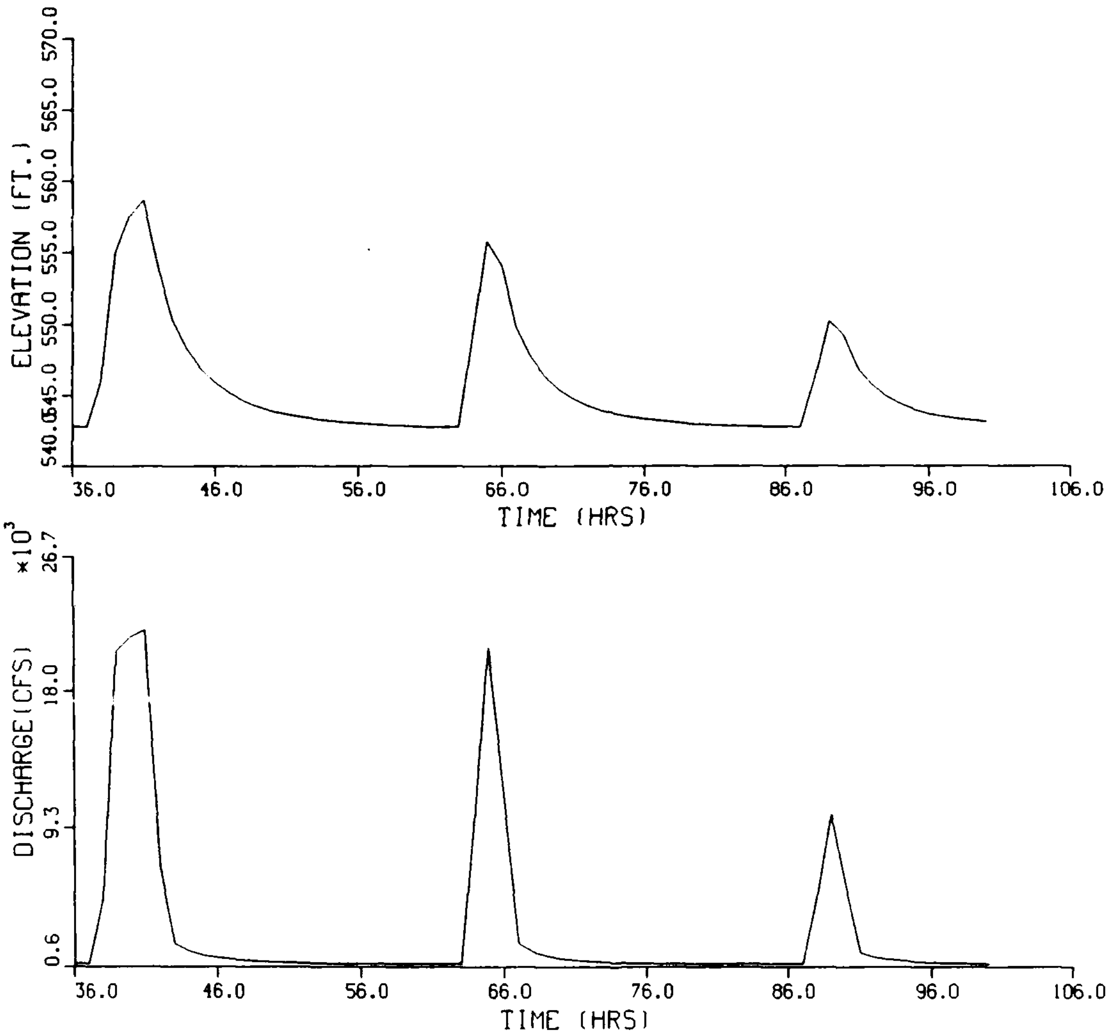

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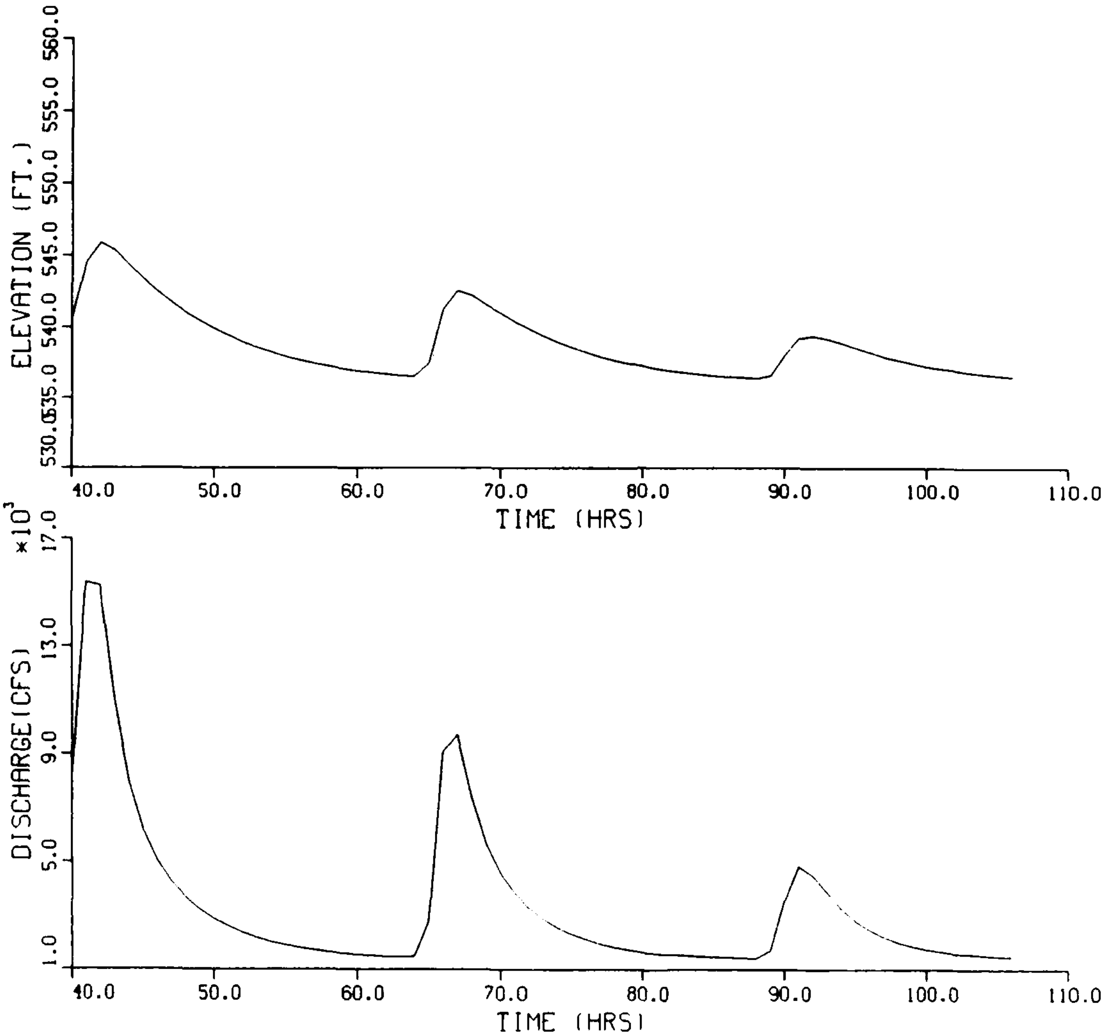

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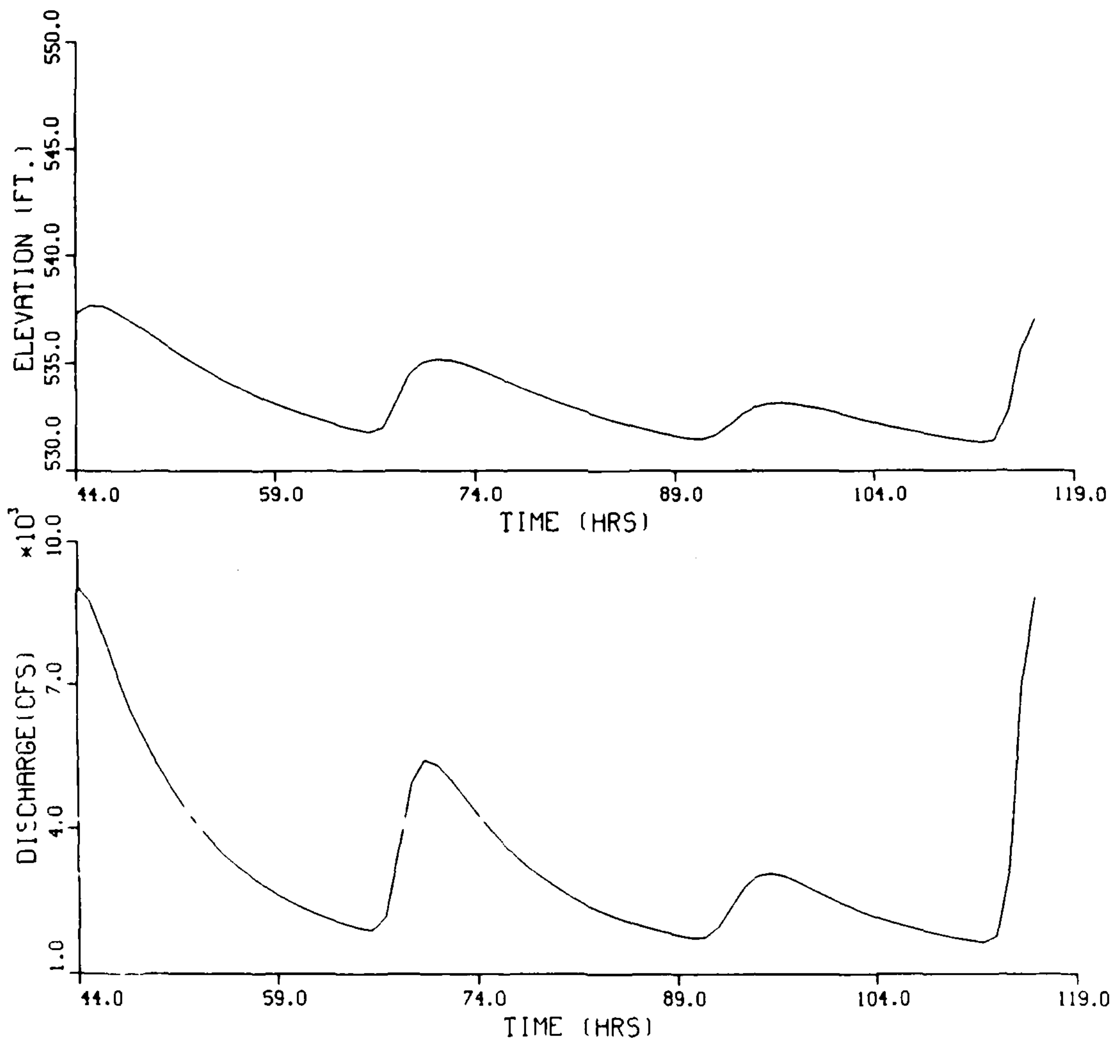

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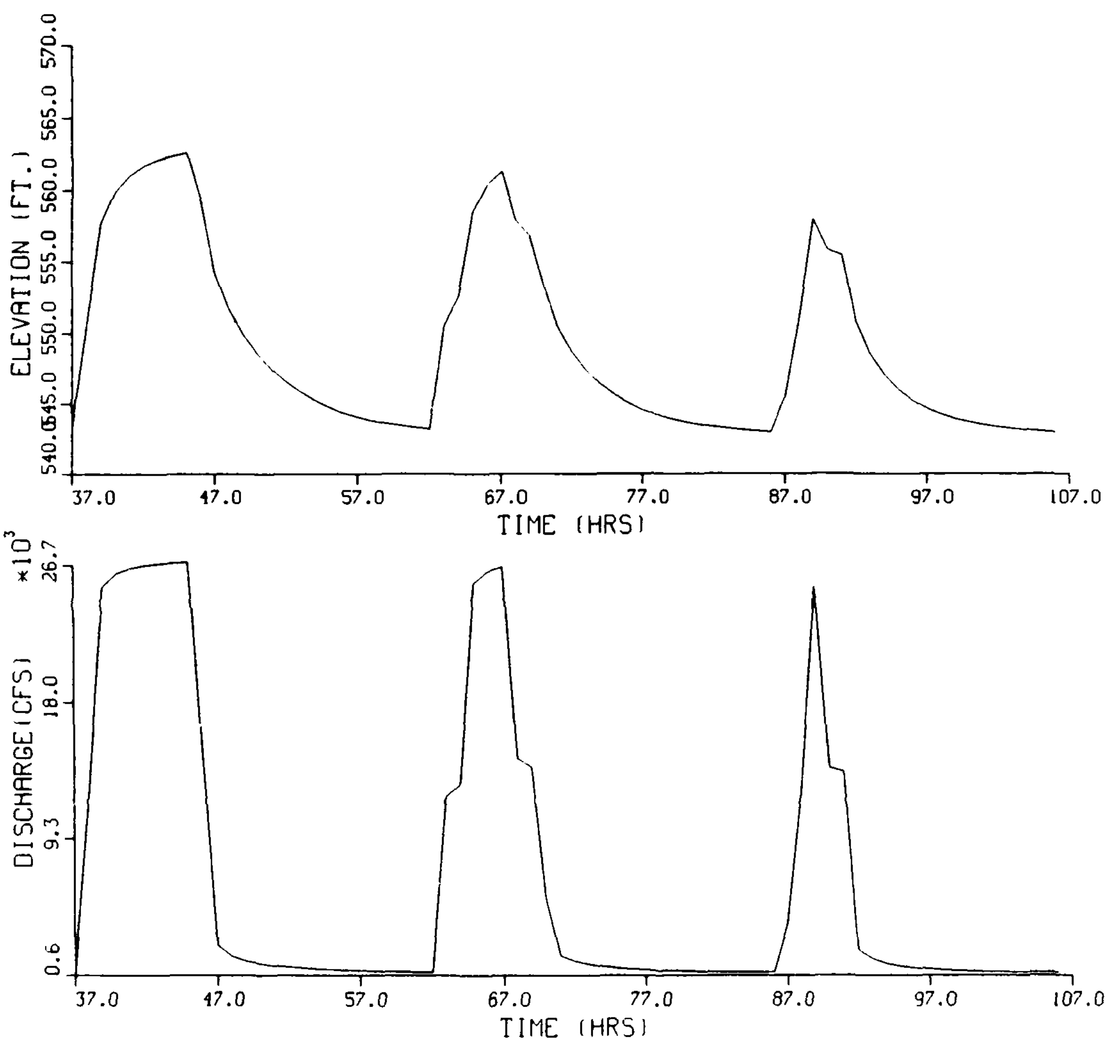

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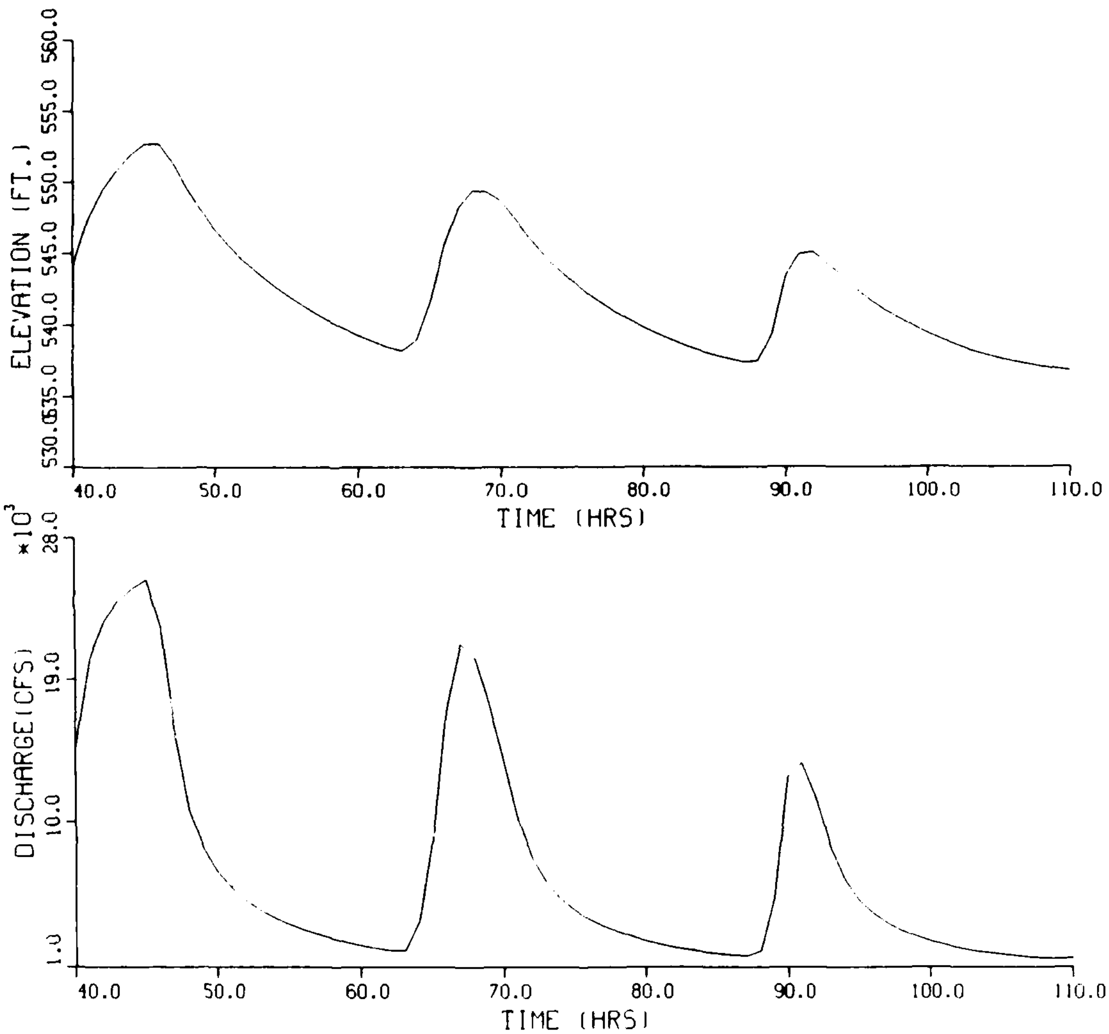

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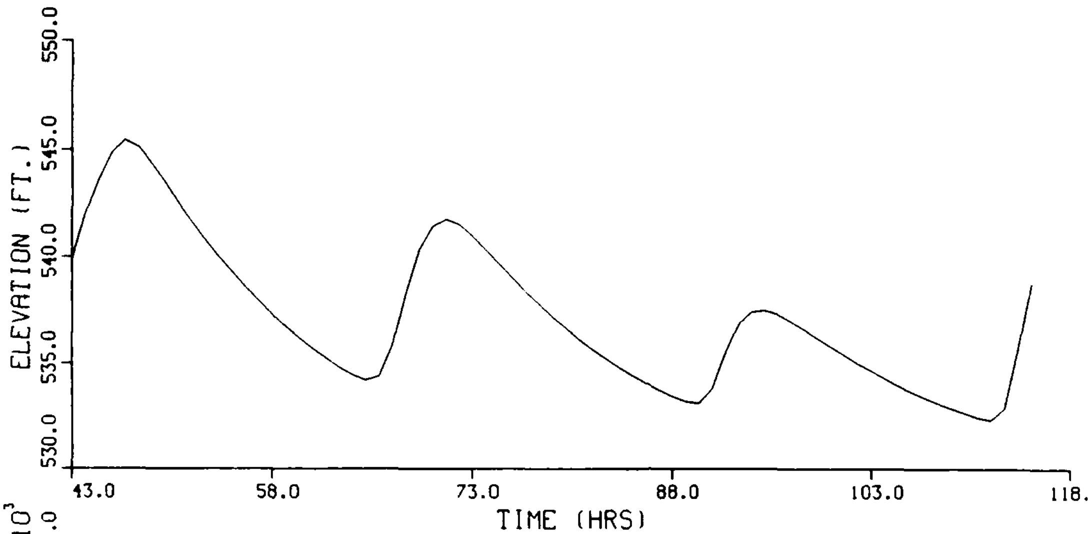

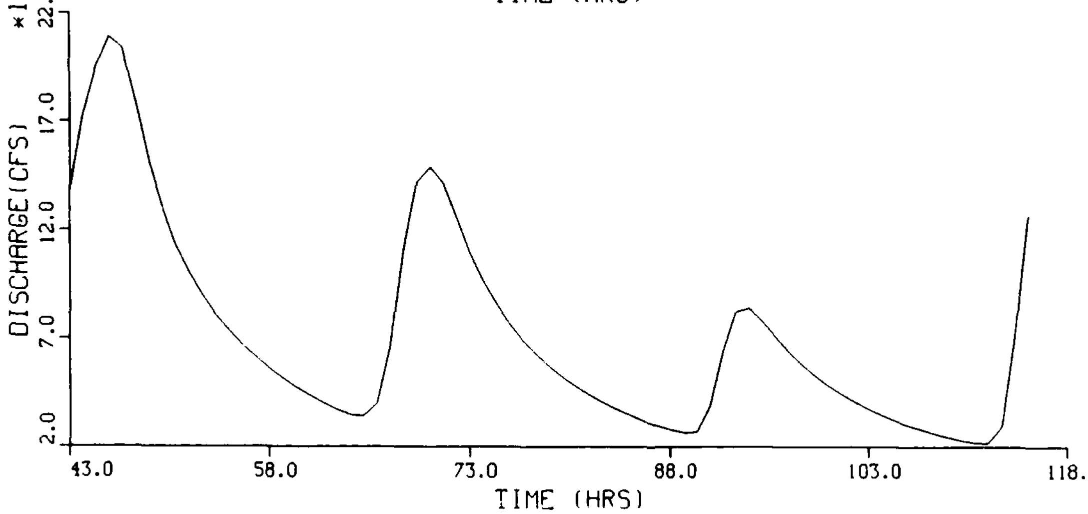

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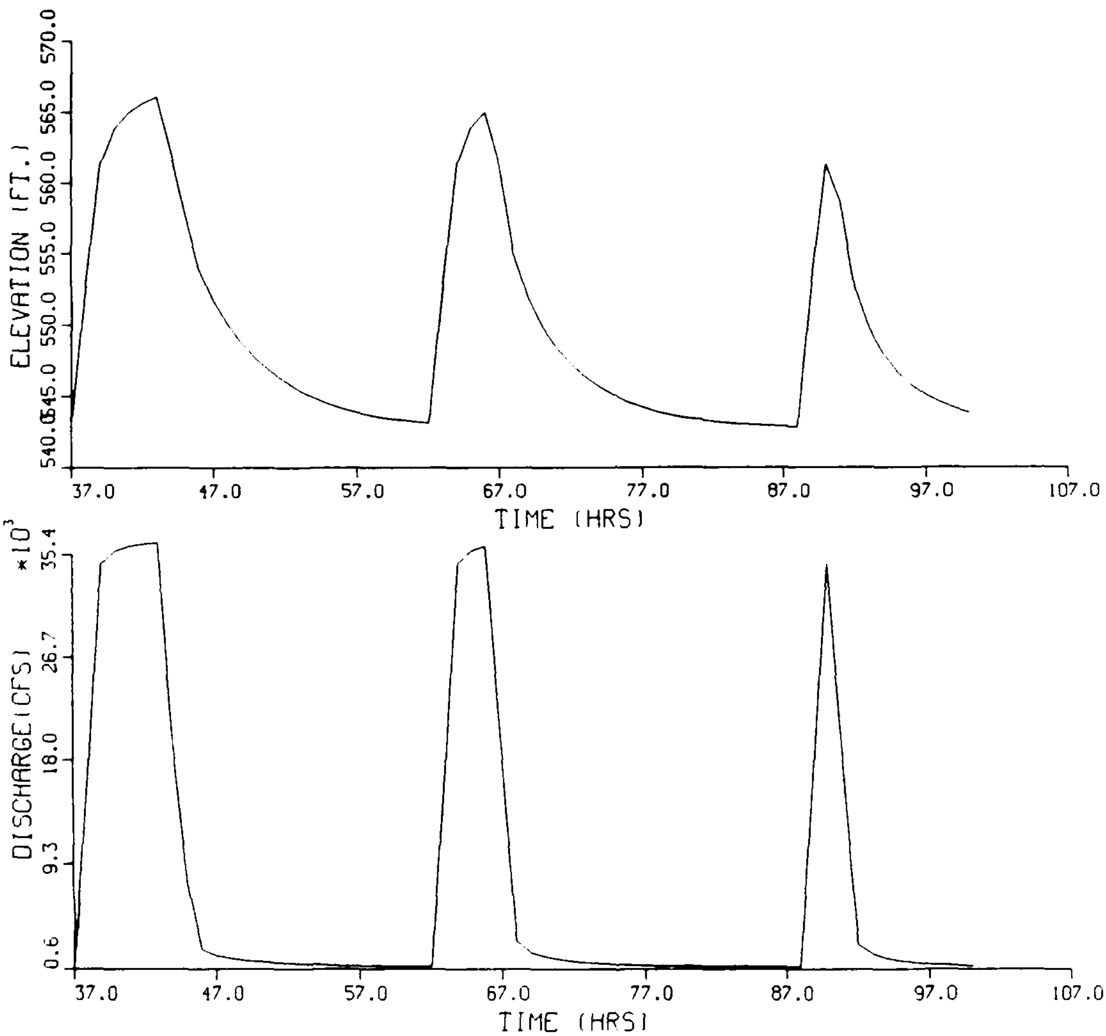

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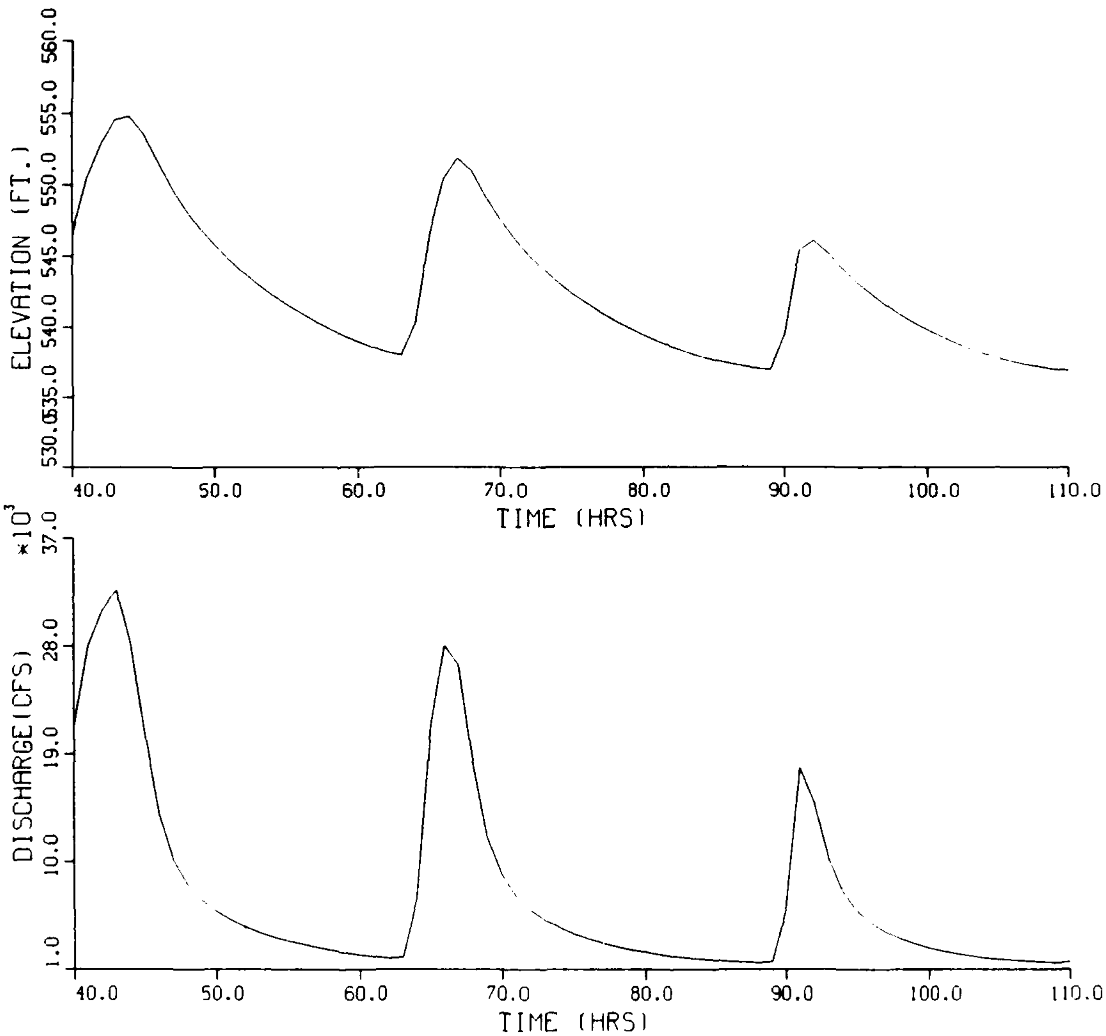

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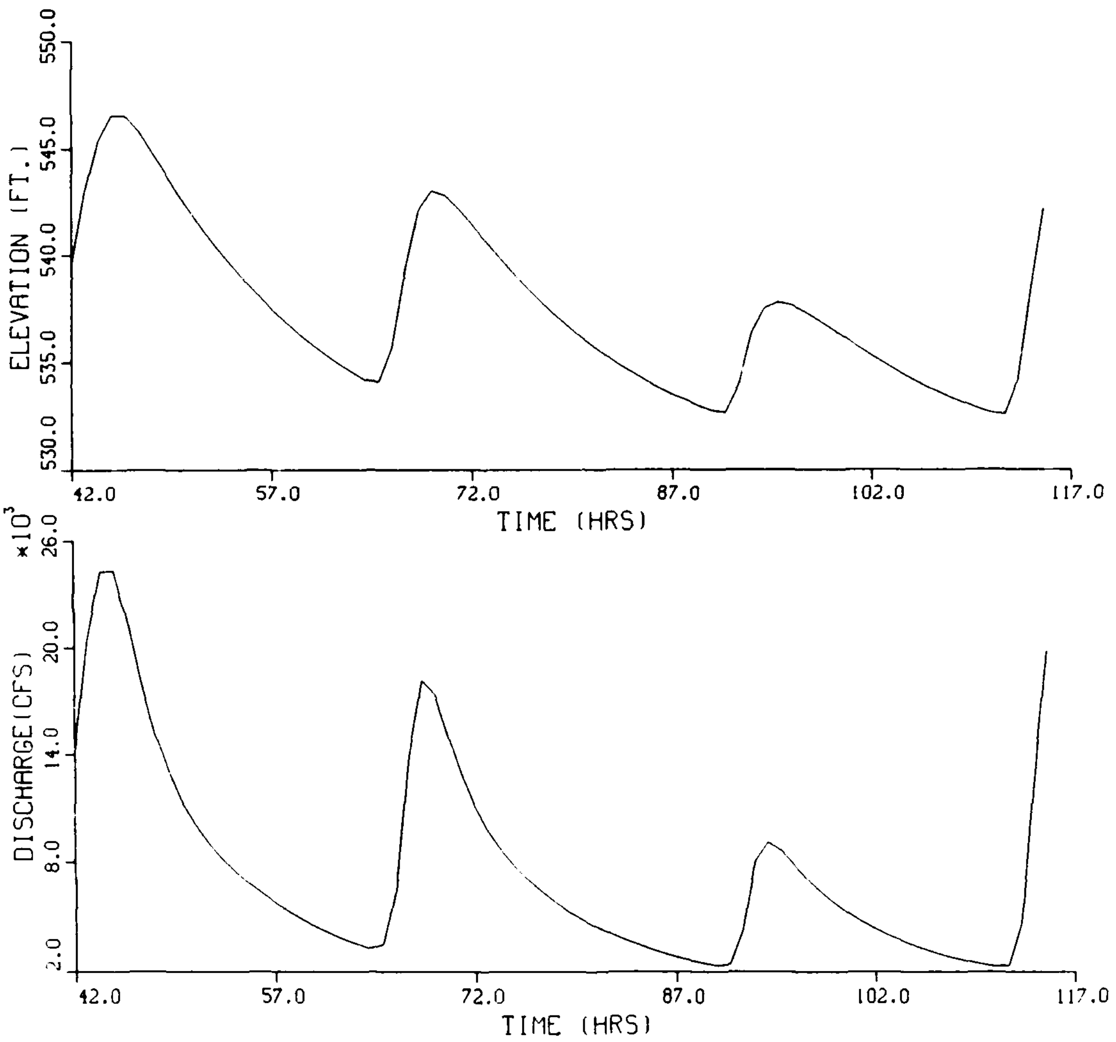

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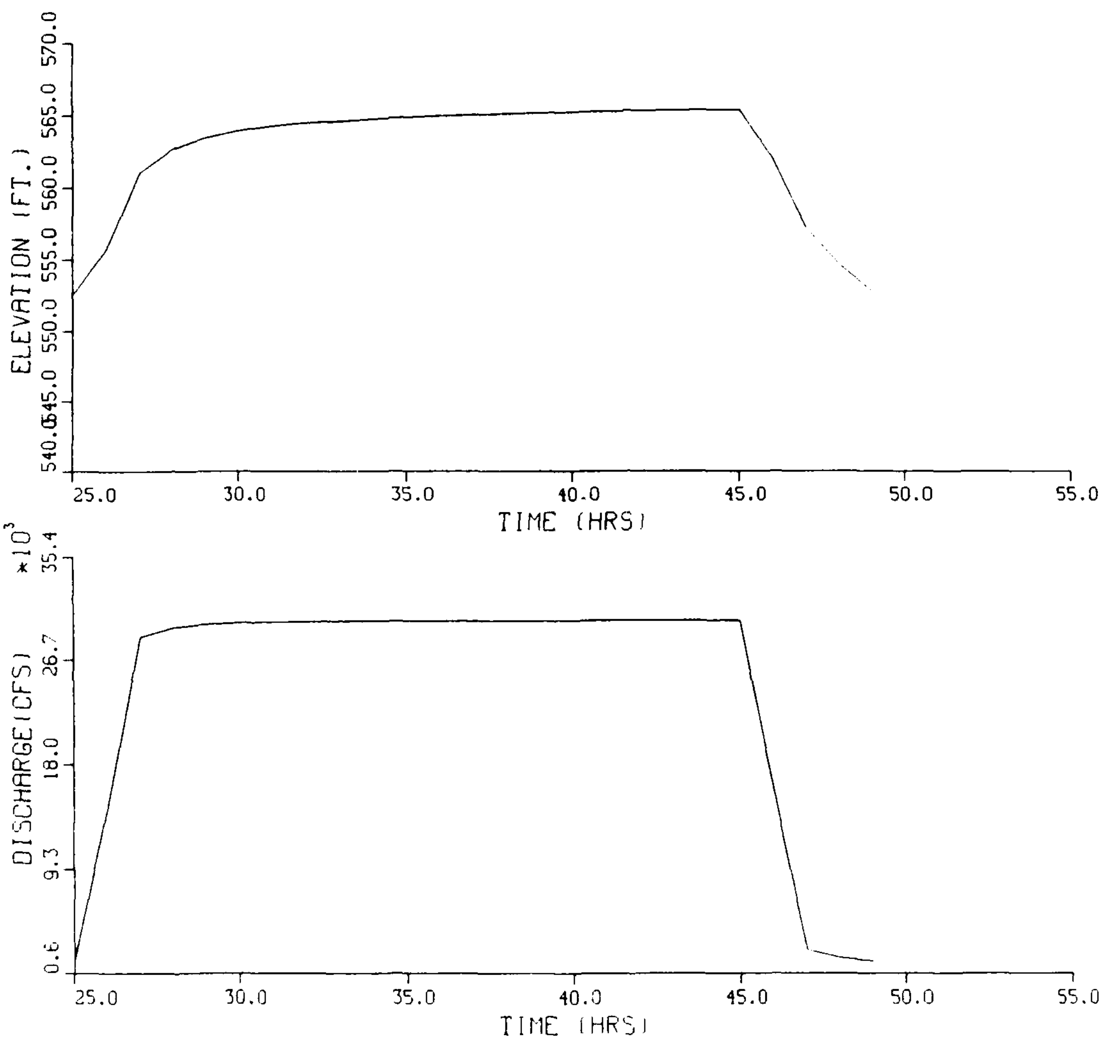

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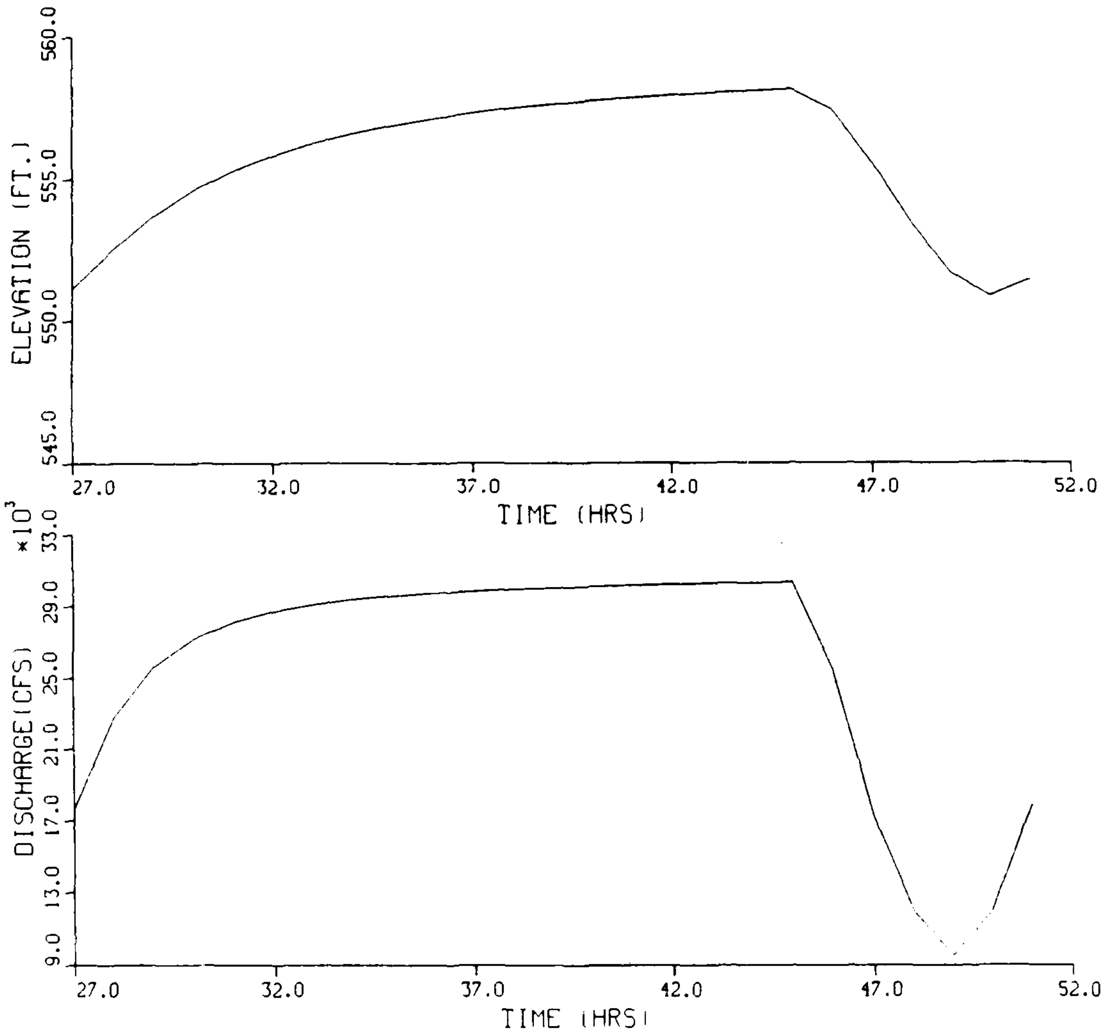

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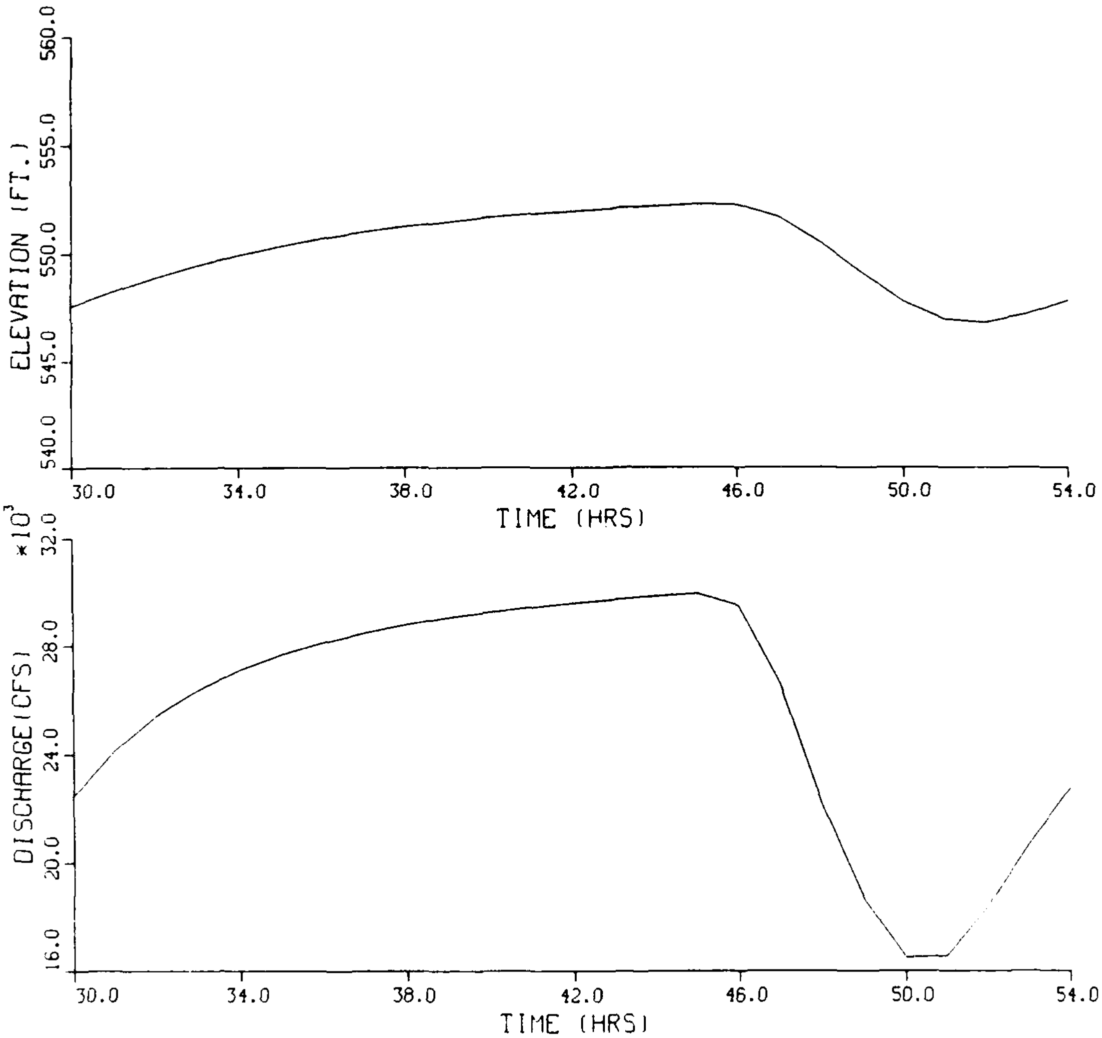

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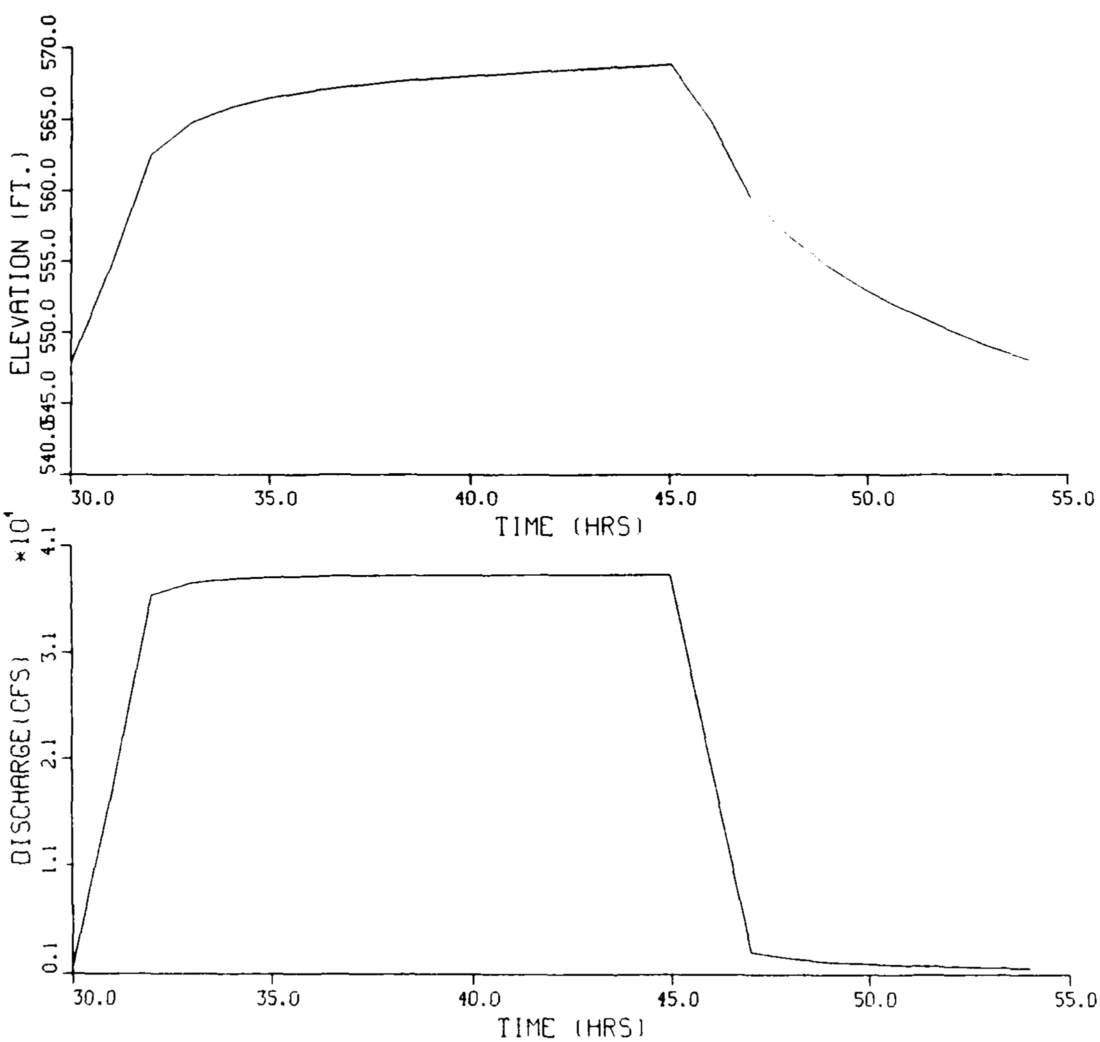

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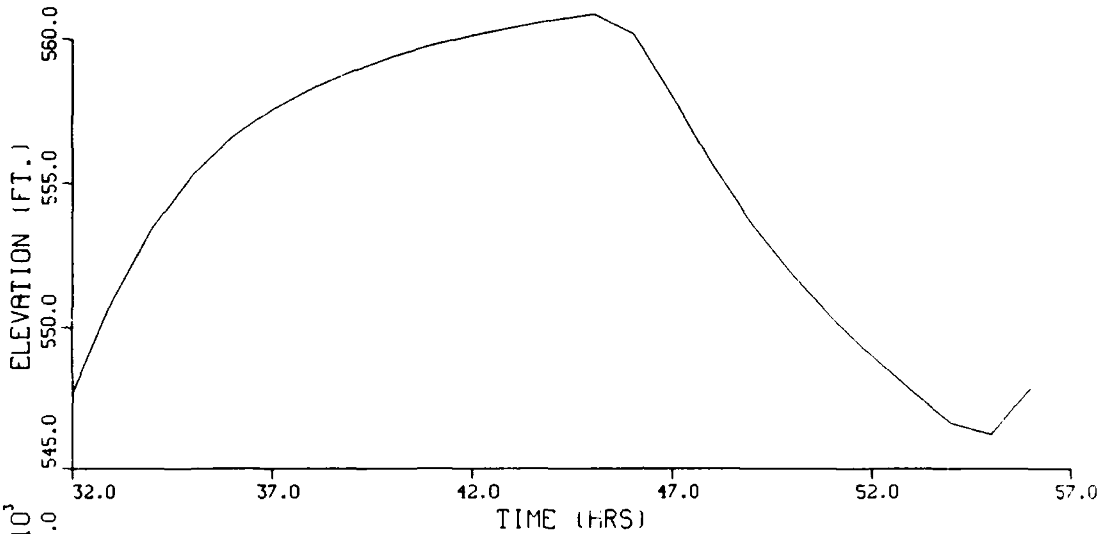

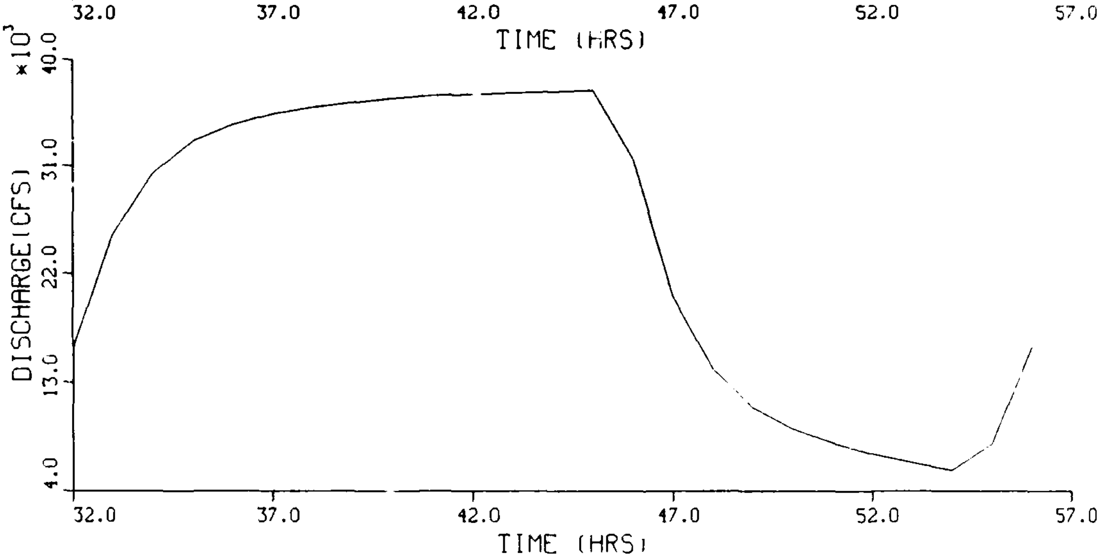

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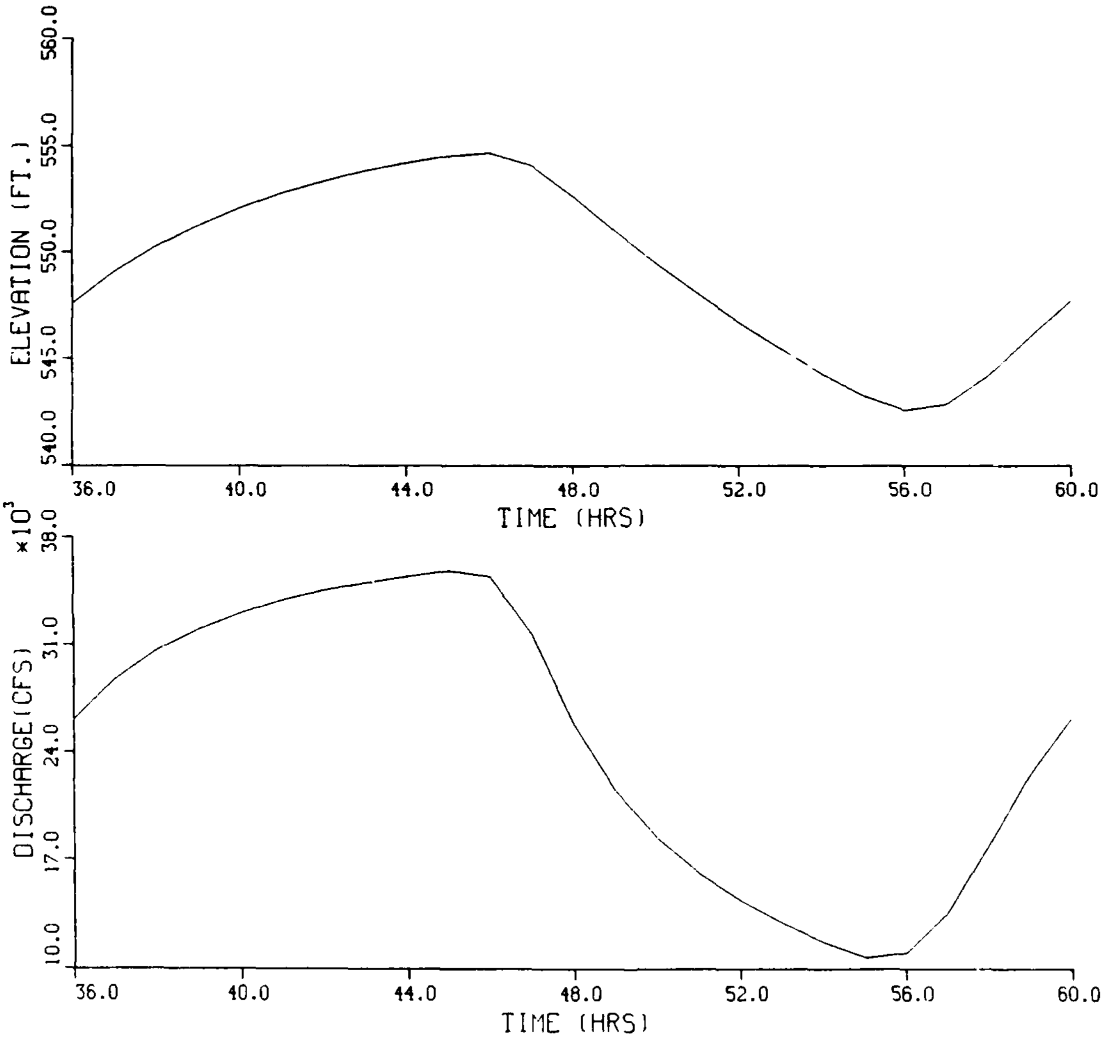
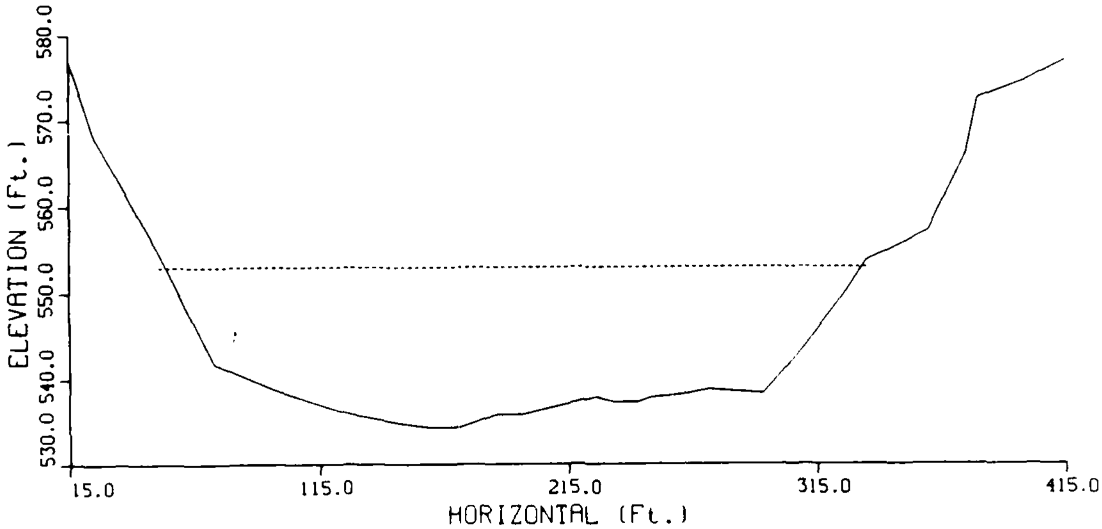
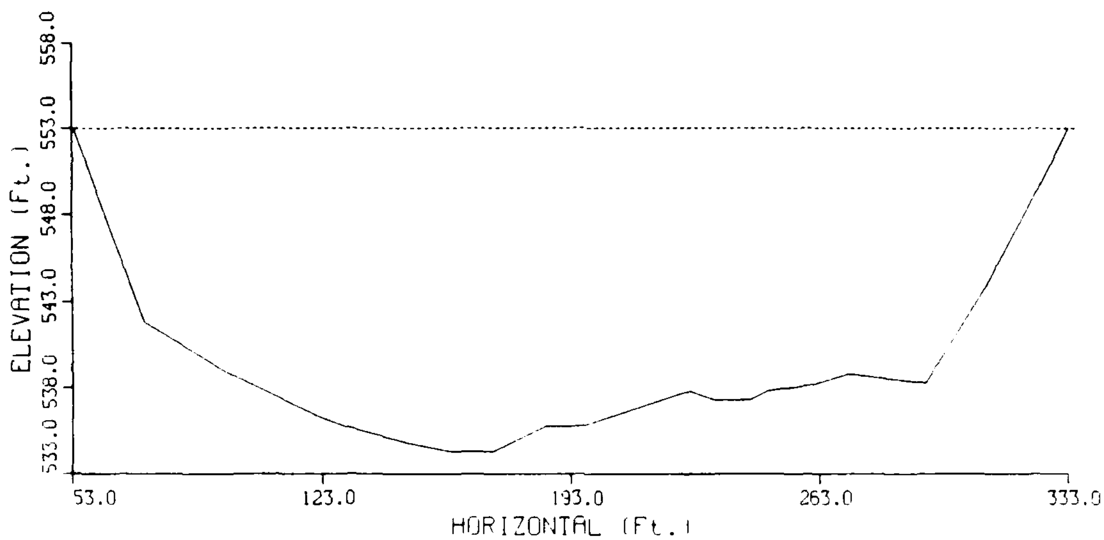


APPENDIX C: CROSS-SECTIONAL VIEWS OF WHOLE VALLEY AND RIVER TRANSECTS USED IN ANALYSIS

(Dotted line represents river surface elevation at approximate median discharge during peaking operations)

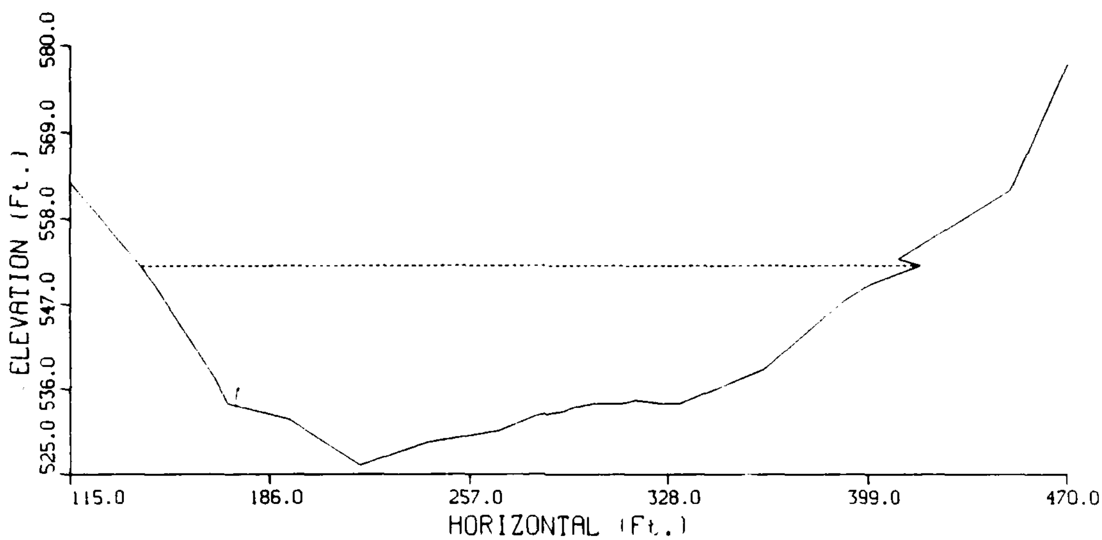


a. Whole valley

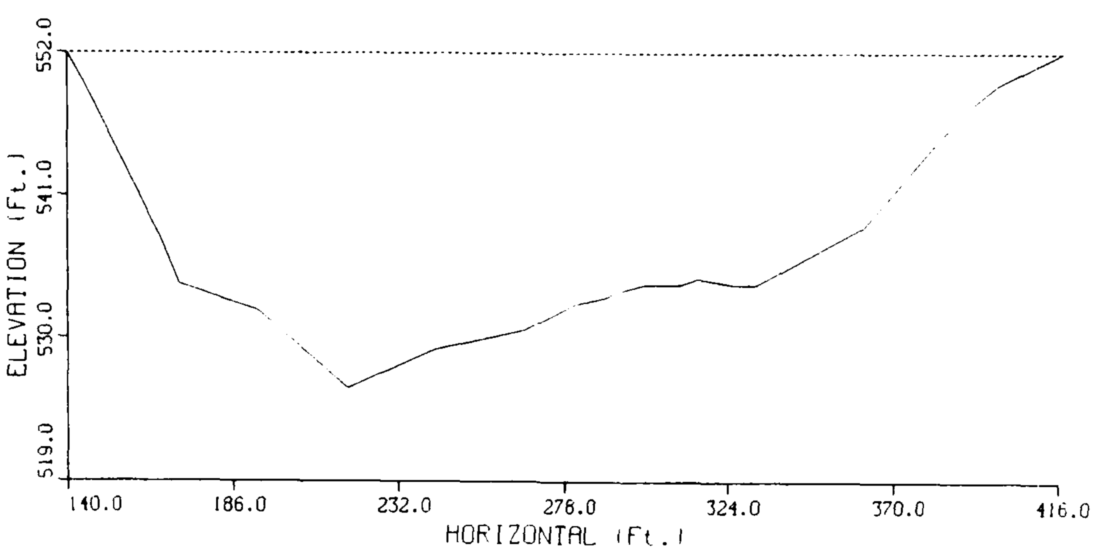


b. River

River Mile 460

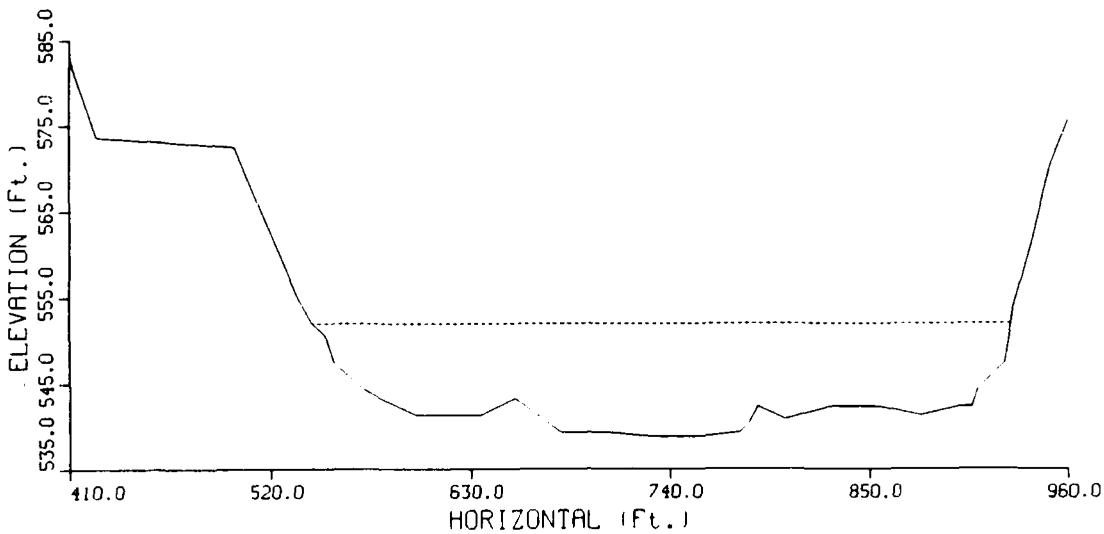


a. Whole valley

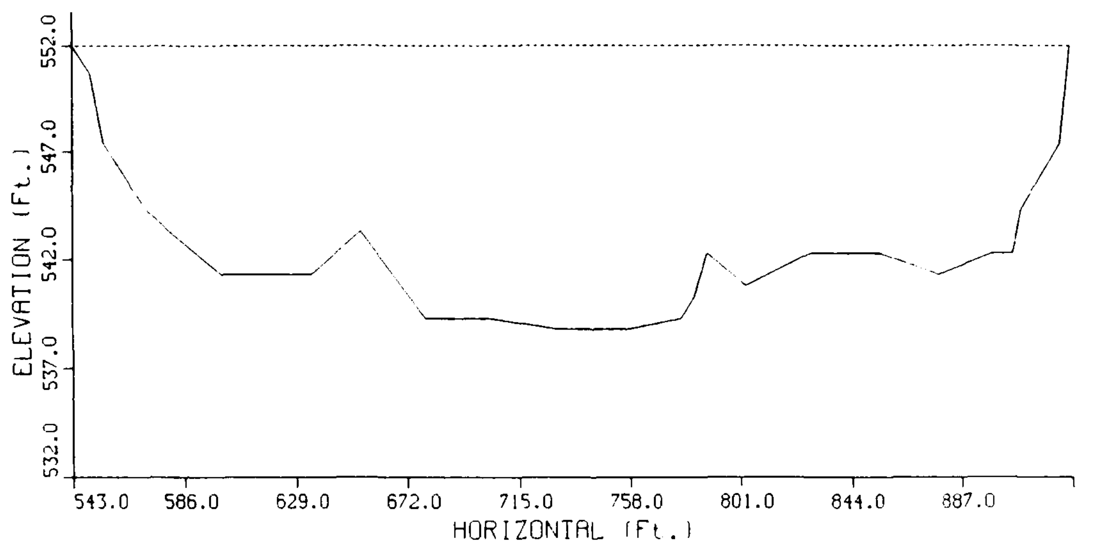


b. River

River Mile 459.26

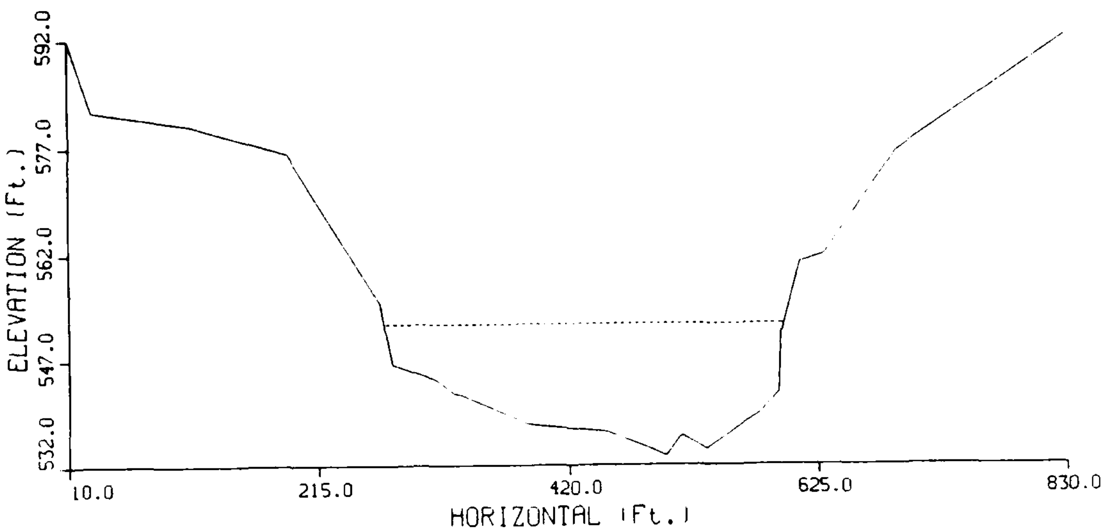


a. Whole valley

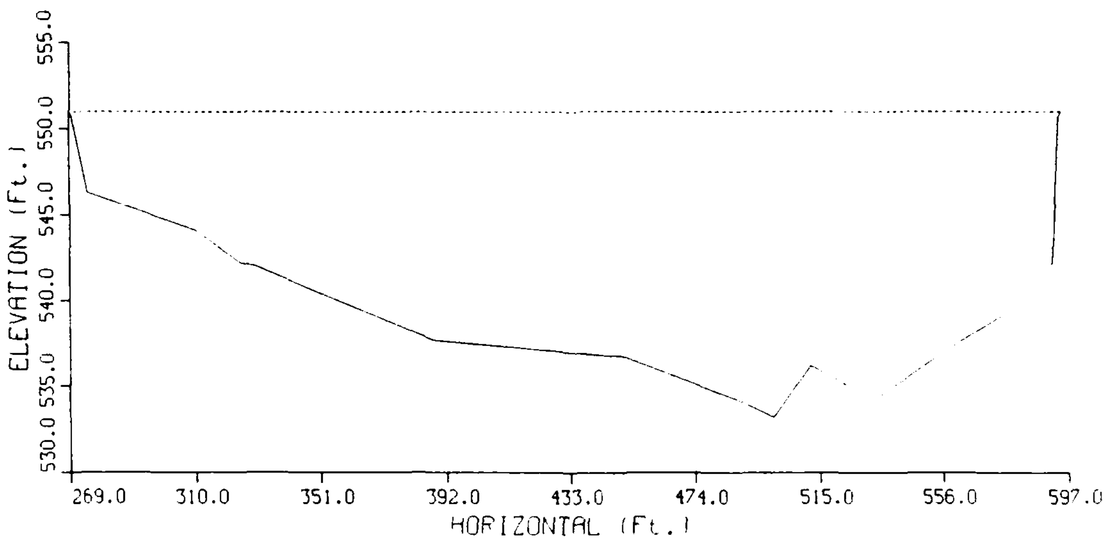


b. River

River Mile 457.40

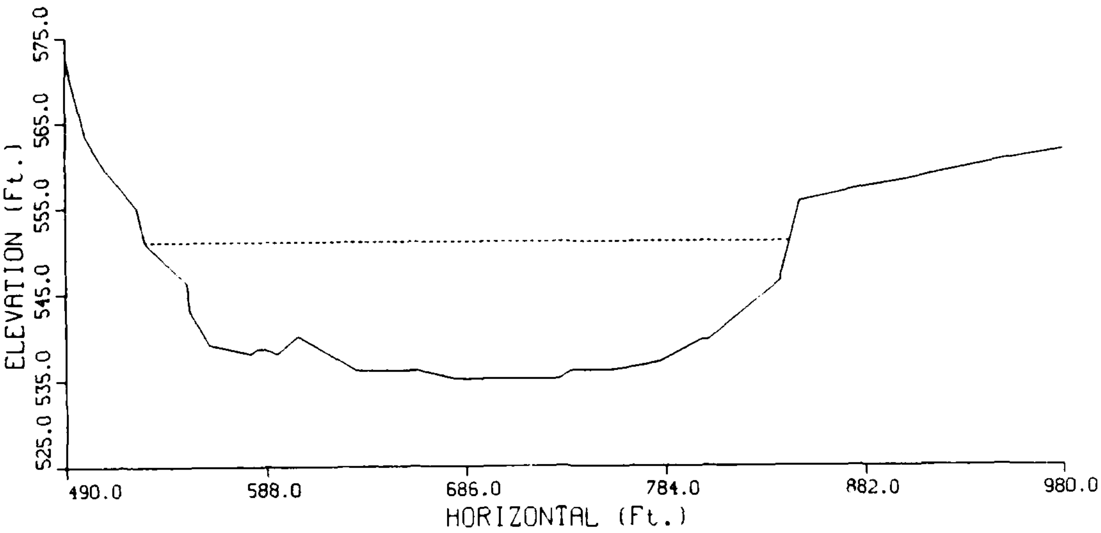


a. Whole valley

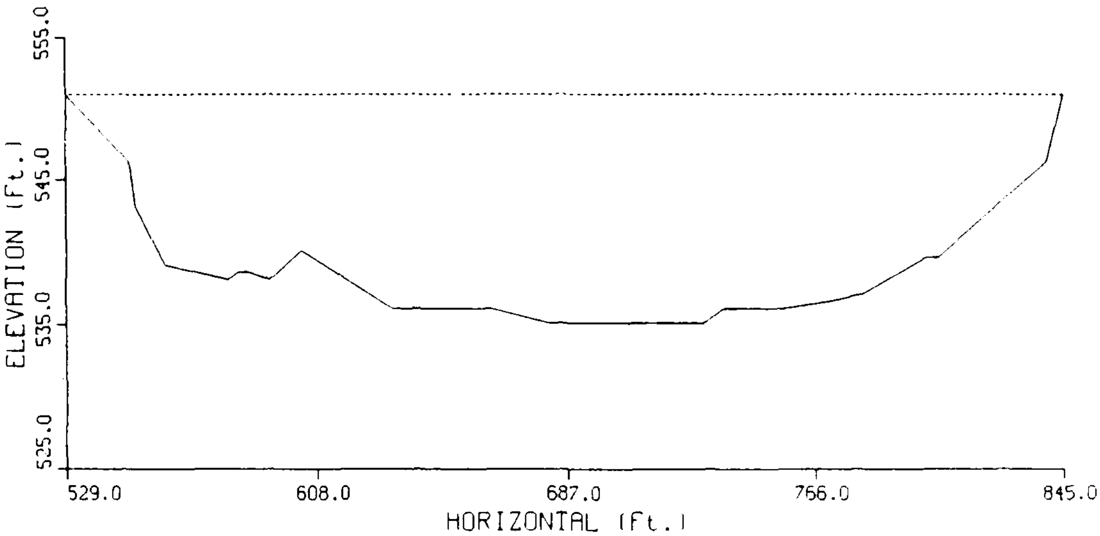


b. River

River Mile 457.16

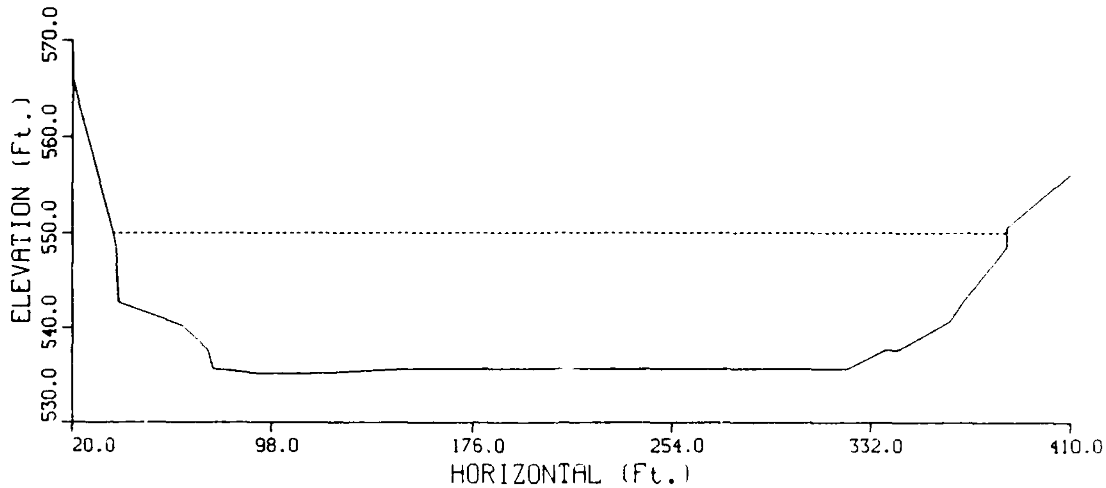


a. Whole valley

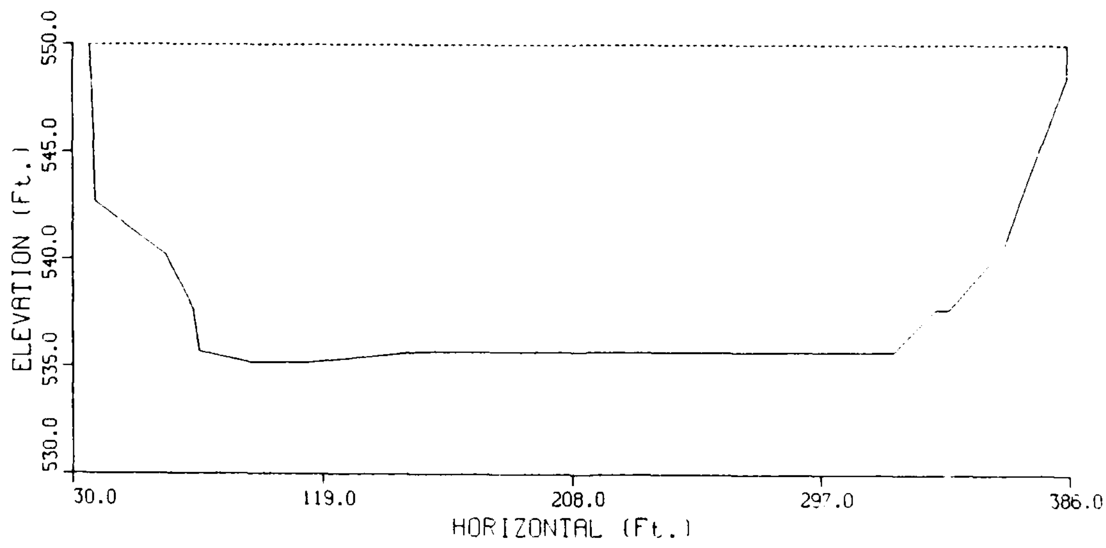


b. River

River Mile 455.9

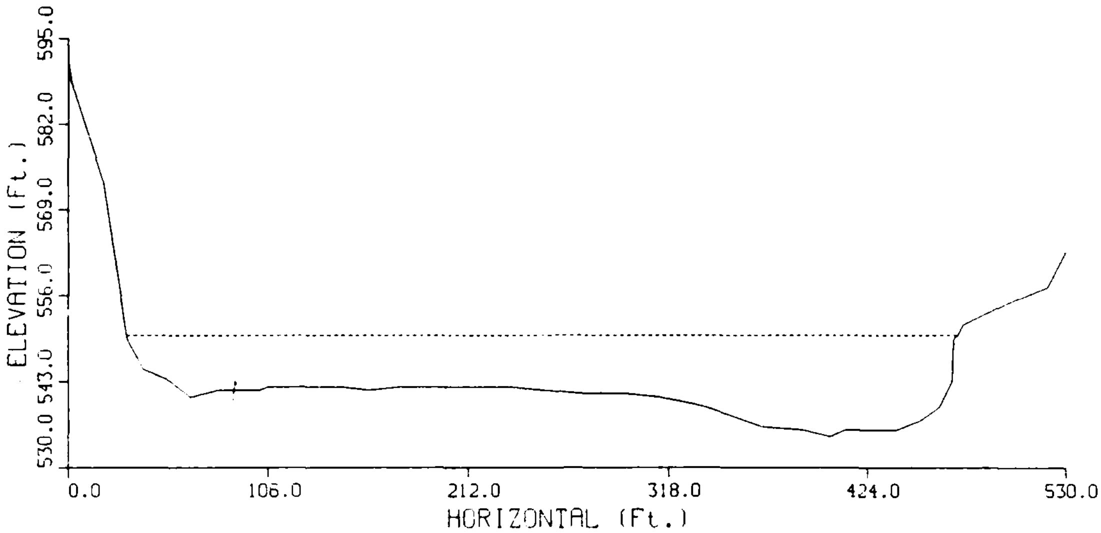


a. Whole valley

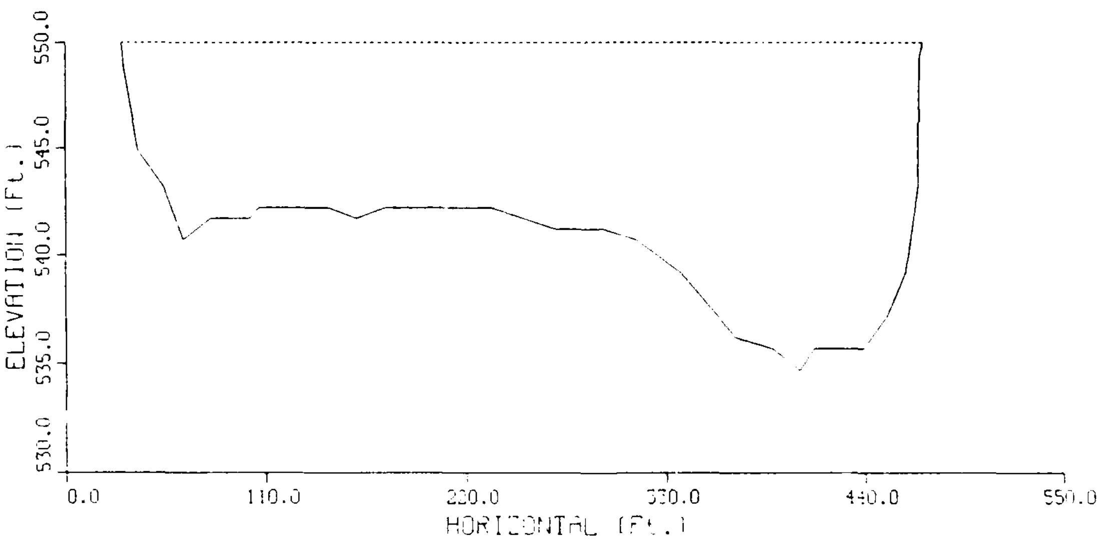


b. River

River Mile 455.1

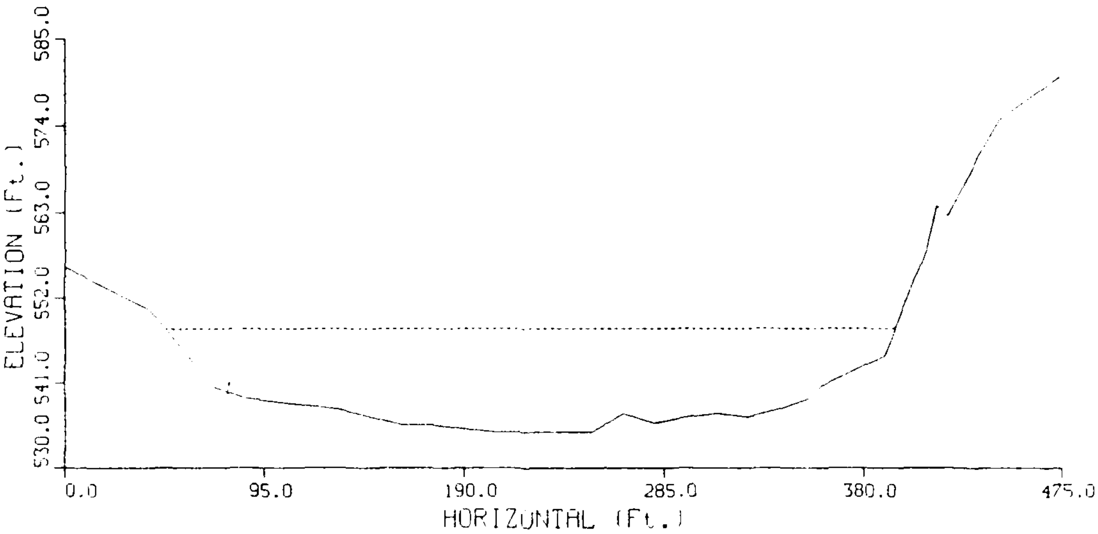


a. Whole valley

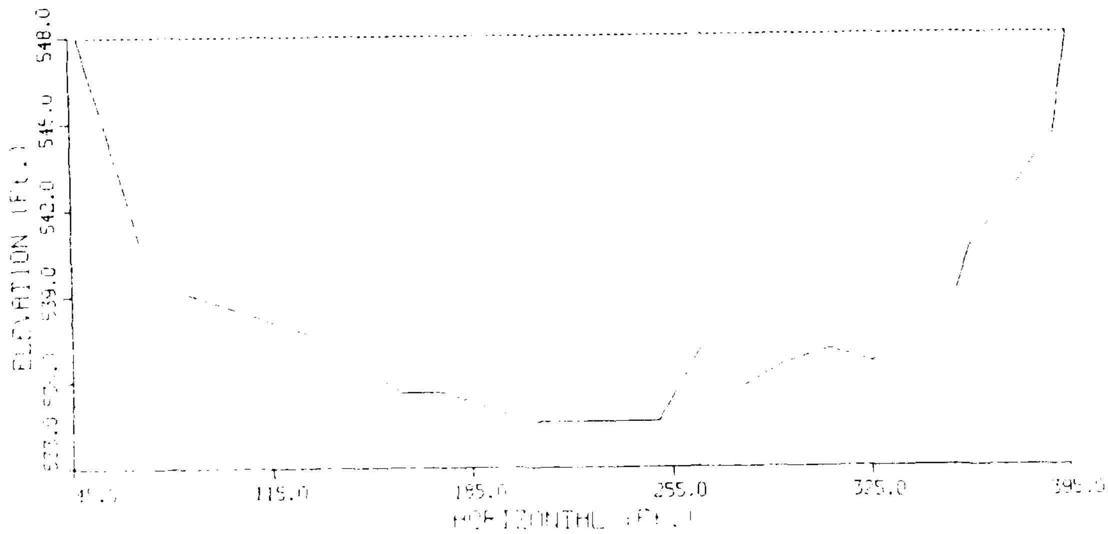


b. River

River Mile 454.7

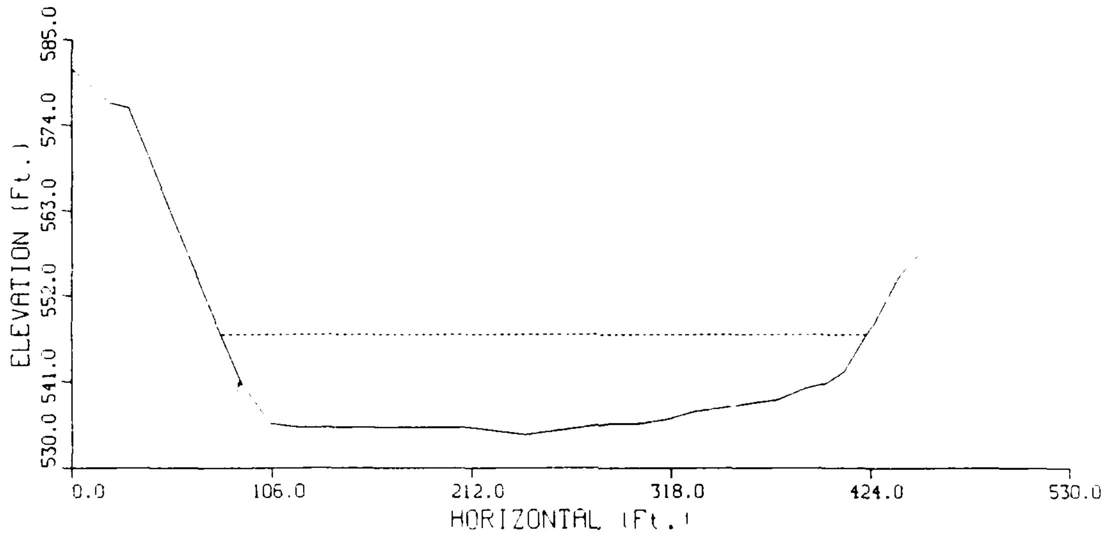


a. Whole valley

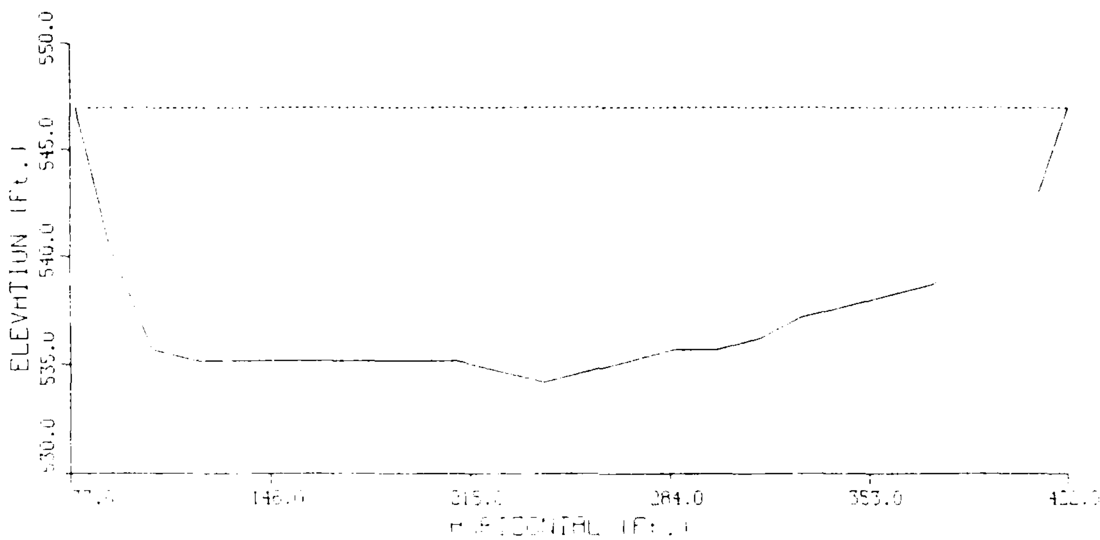


b. River

River Mile 453.18

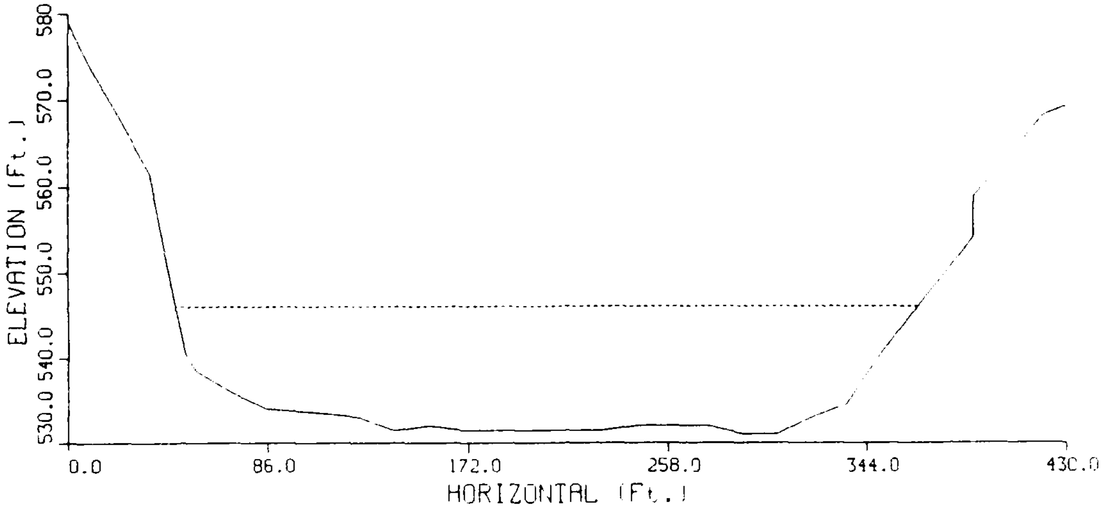


a. Whole valley

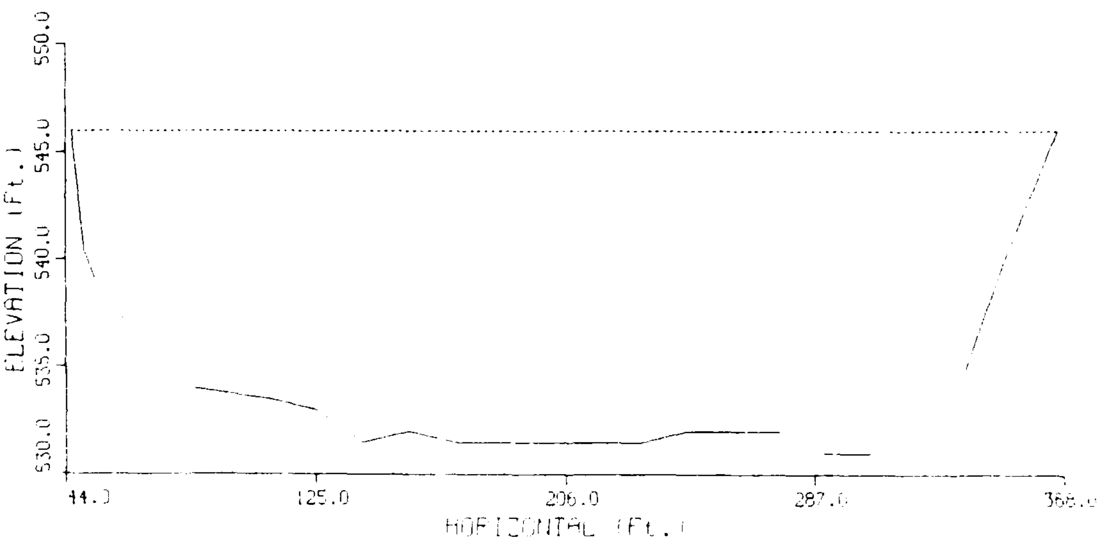


b. River

River Mile 452.76

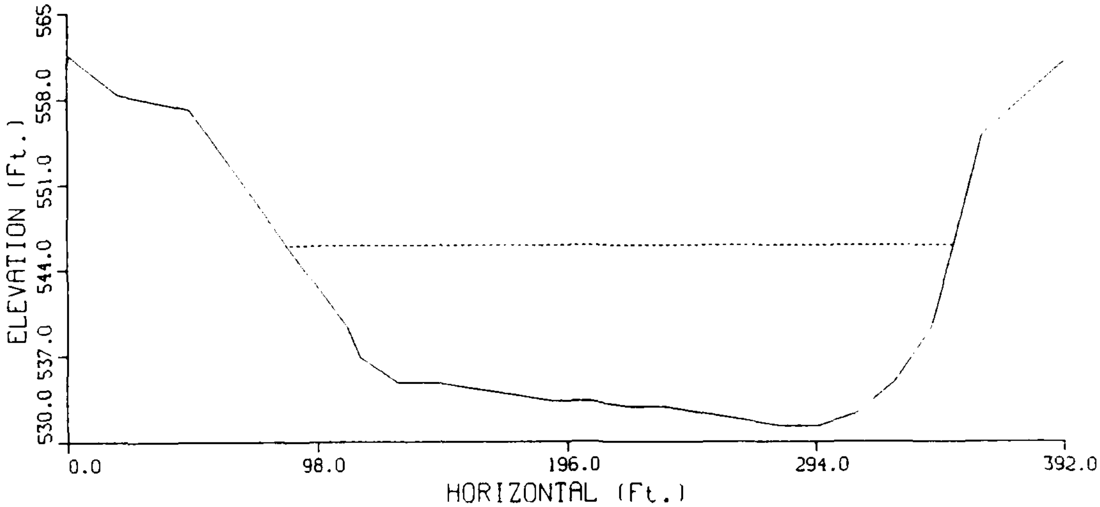


a. Whole valley

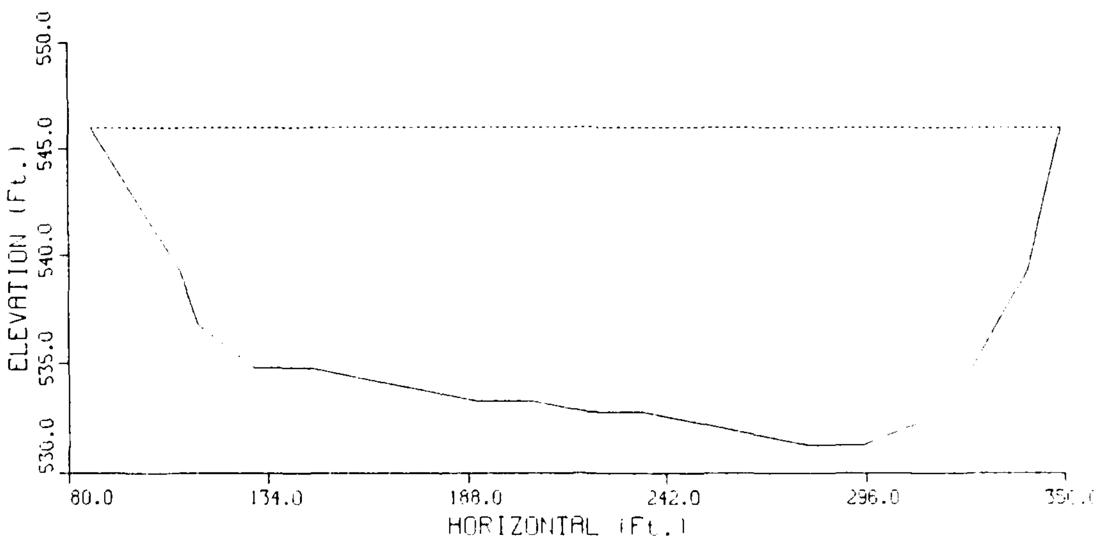


b. River

River Mile 451.7

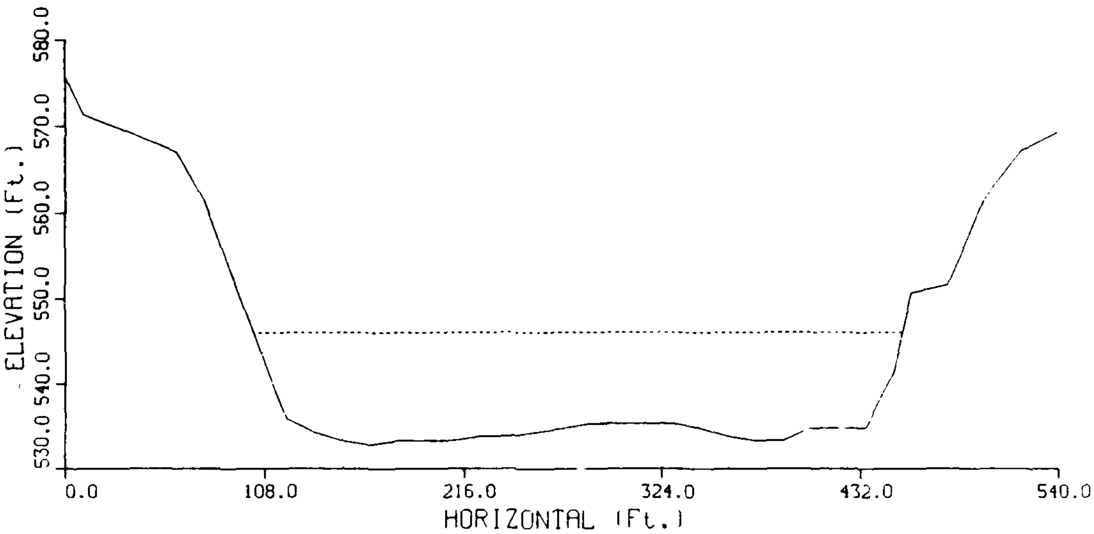


a. Whole valley

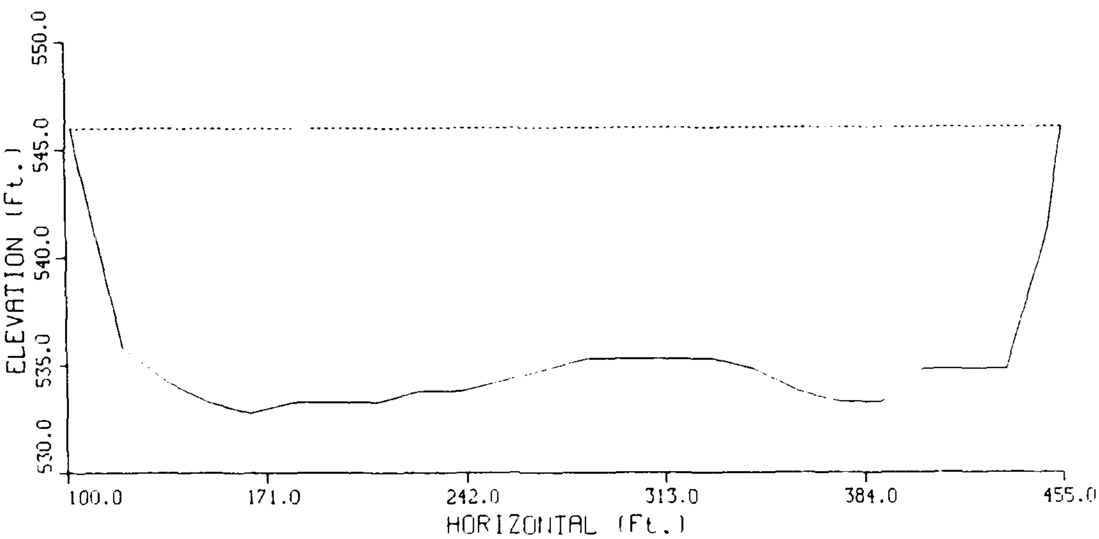


b. River

River Mile 451.2

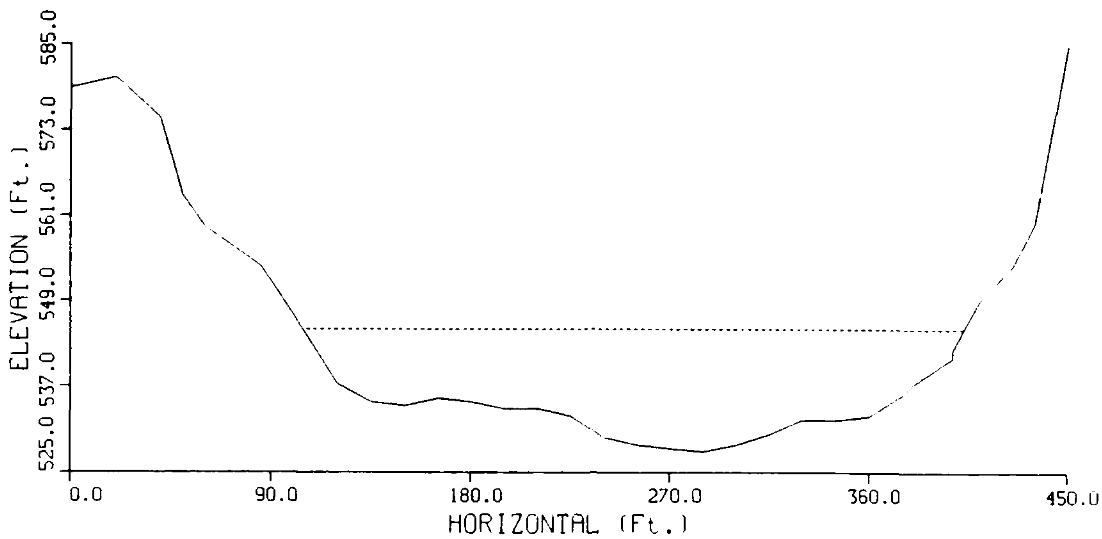


a. Whole valley

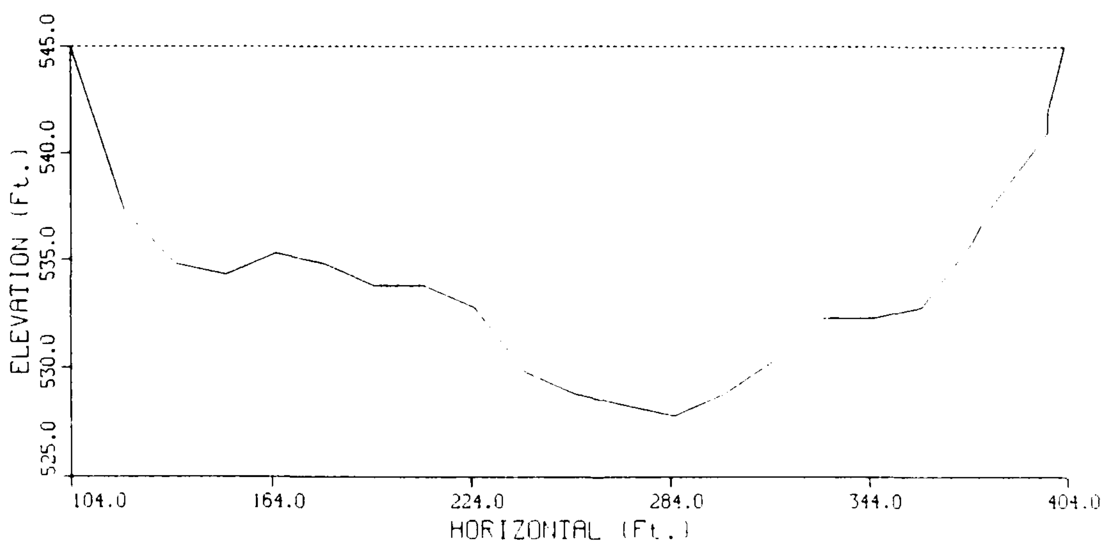


b. River

River Mile 450.95

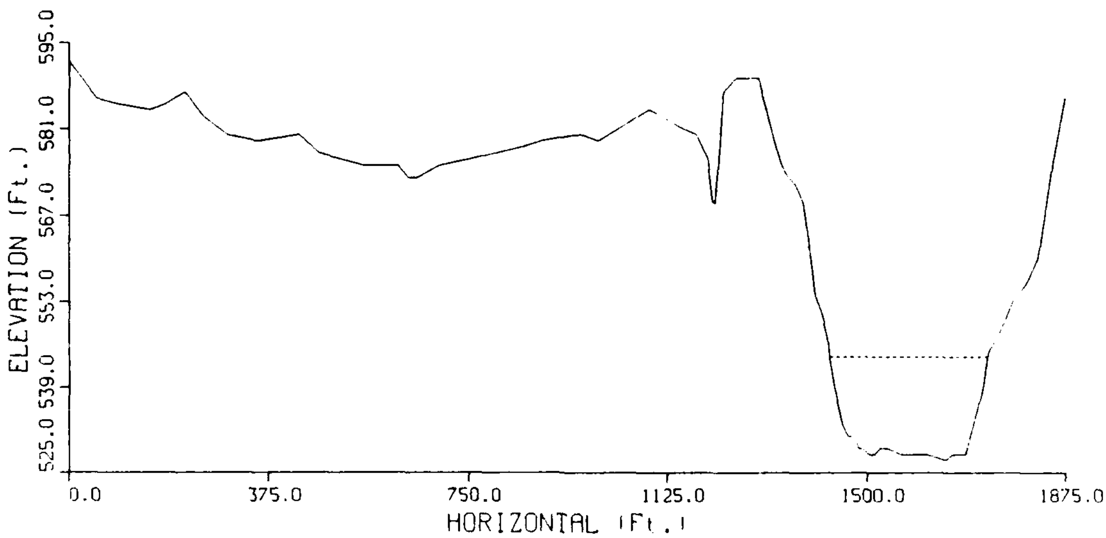


a. Whole valley

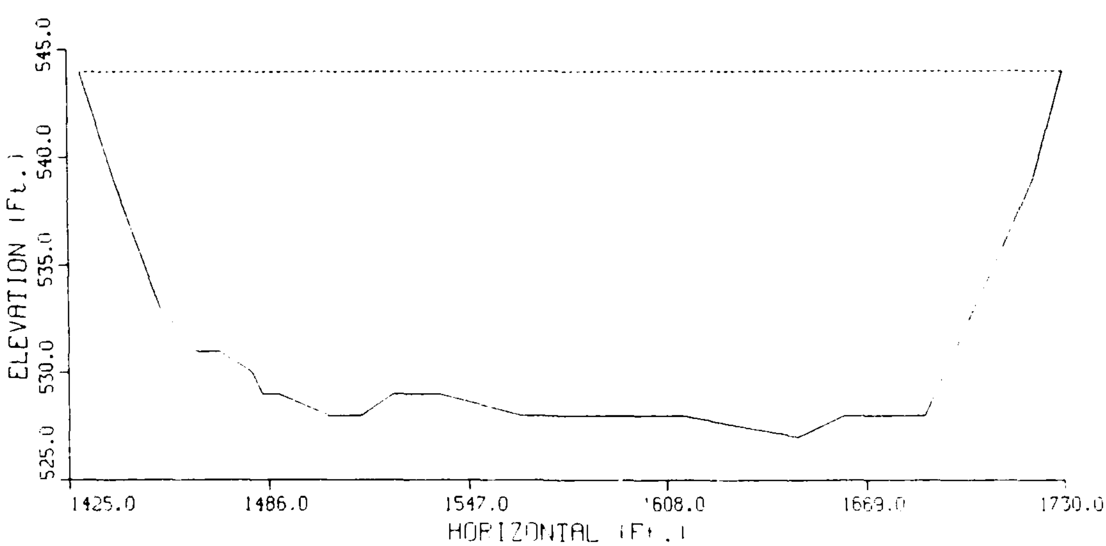


b. River

River Mile 450.2

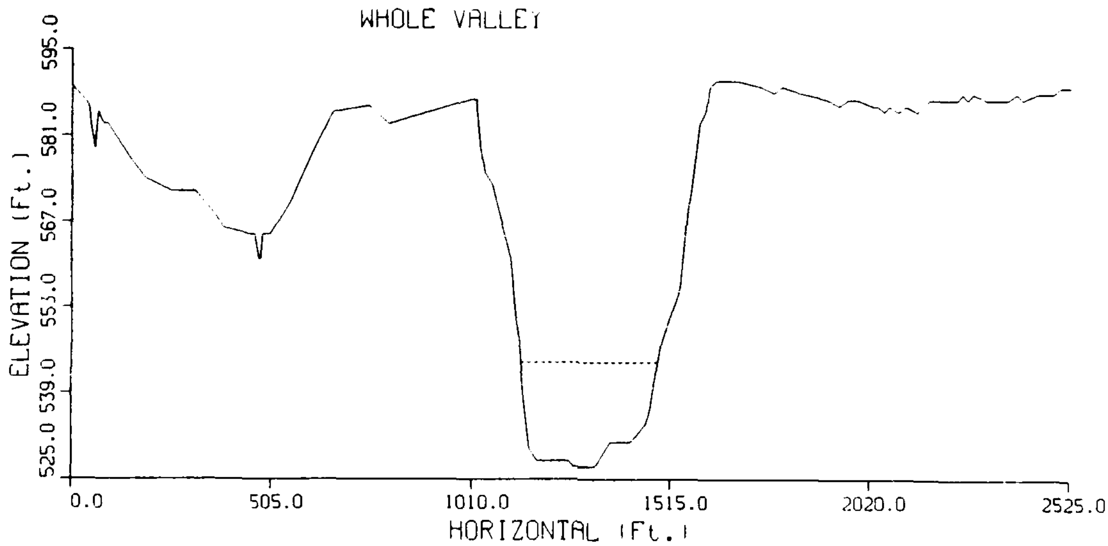


a. Whole valley

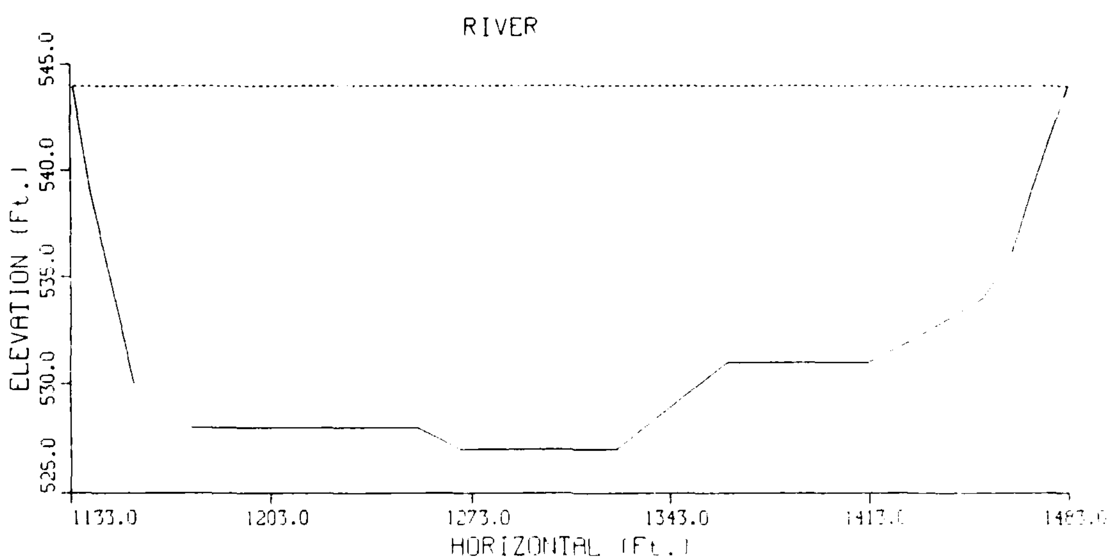


b. River

River Mile 449.4

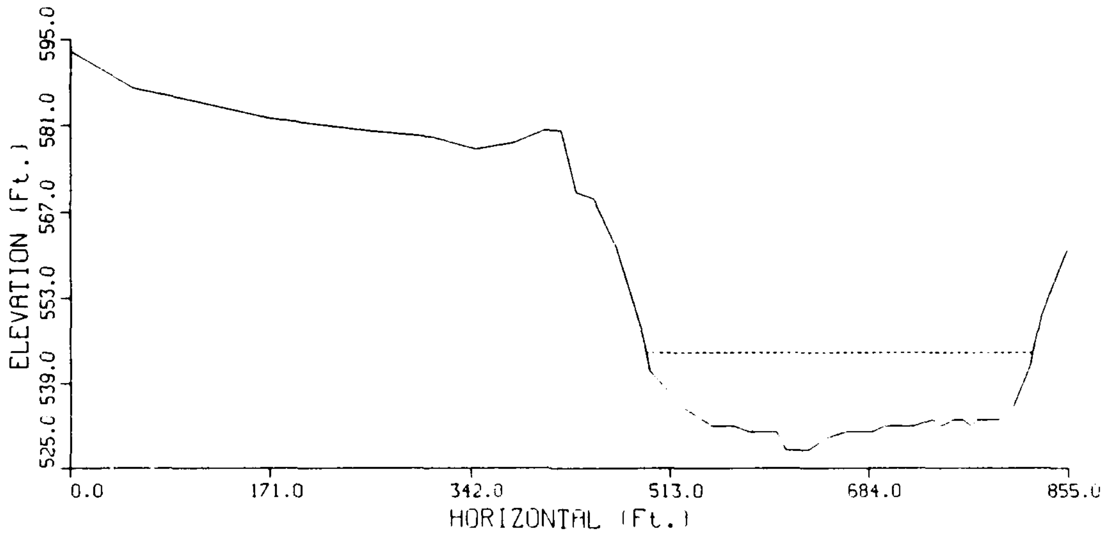


a. **Whole valley**

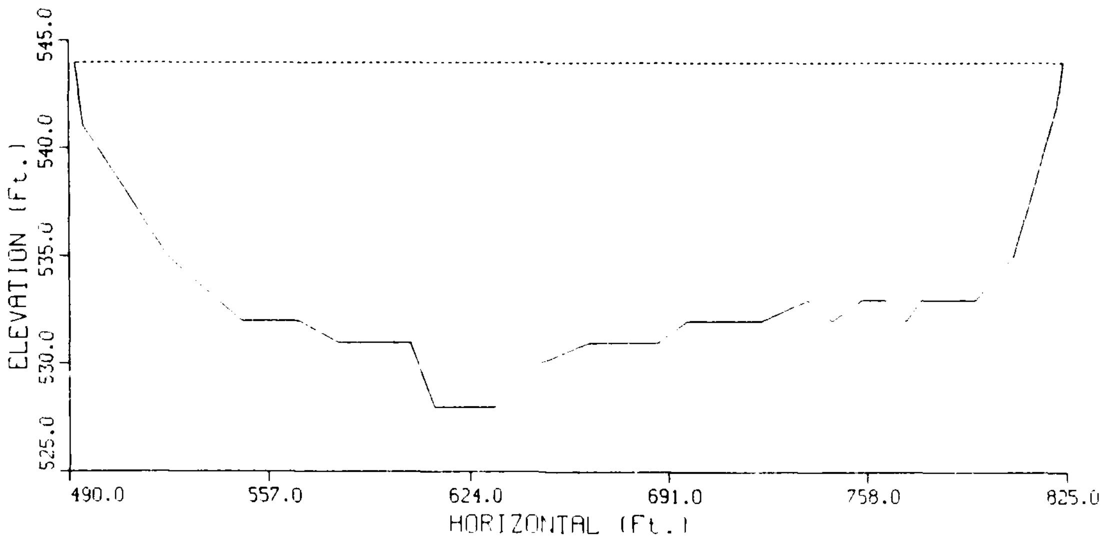


b. River

River Mile 448.5

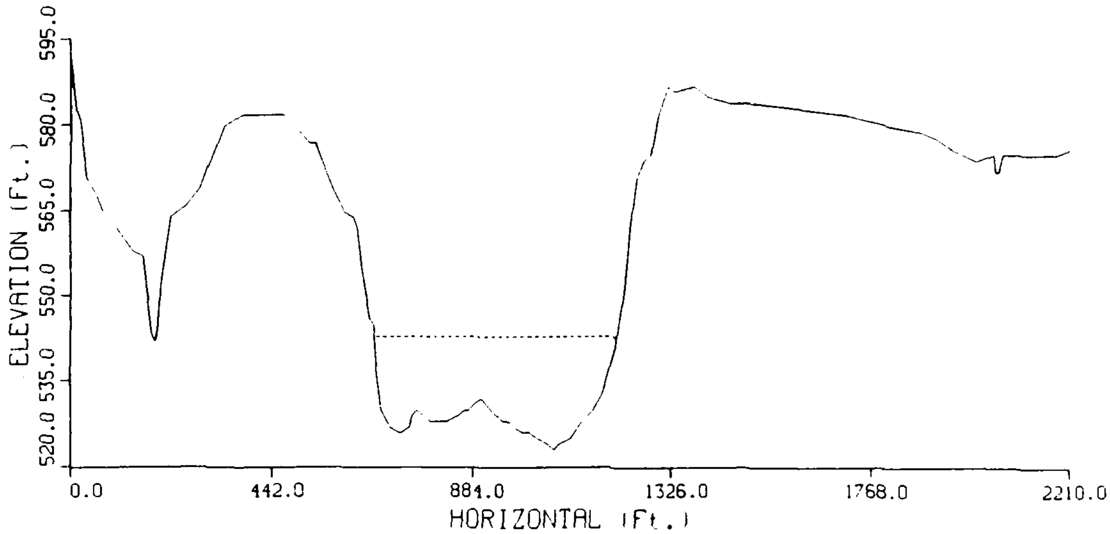


a. Whole valley

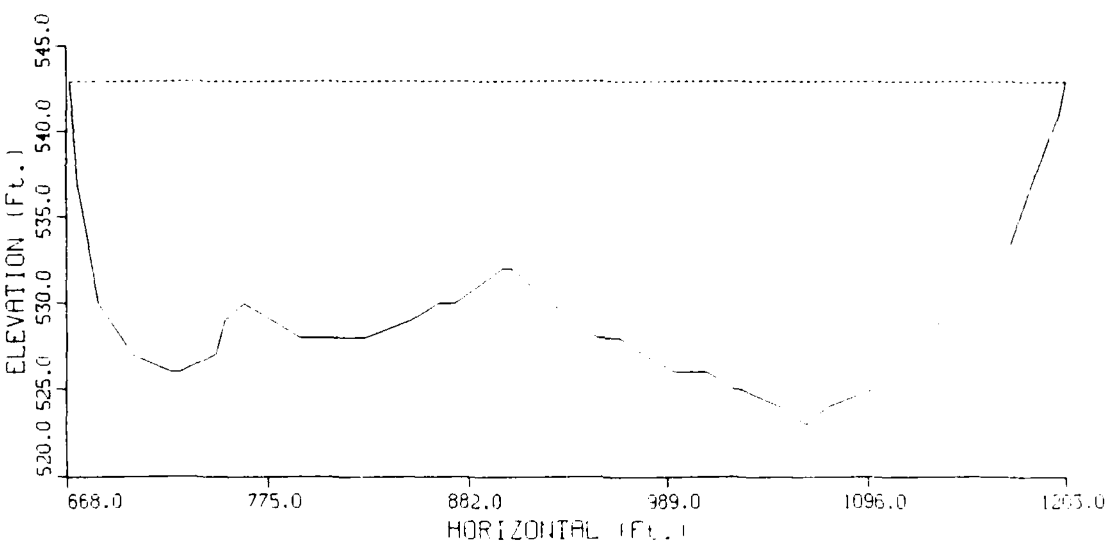


b. River

River Mile 448.07

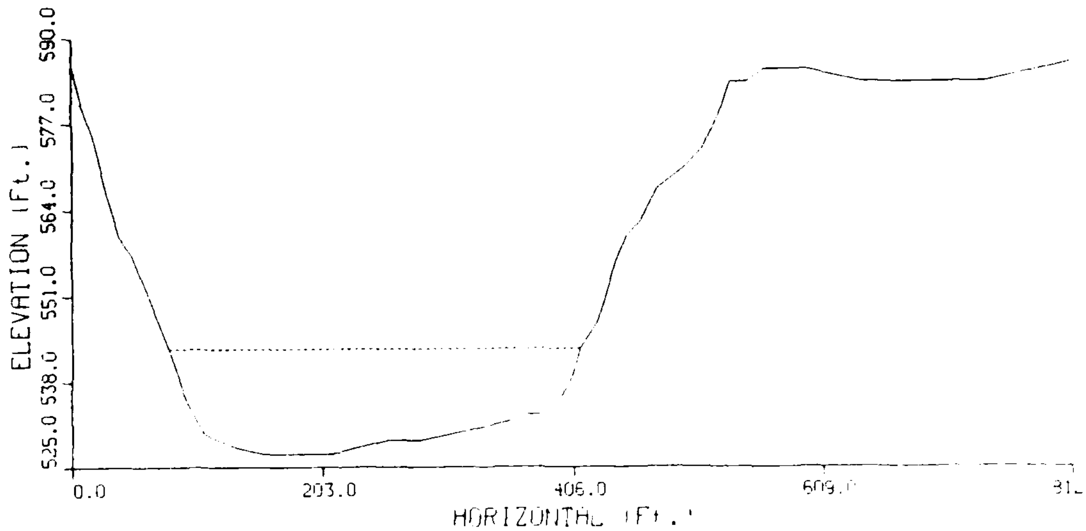


a. Whole valley

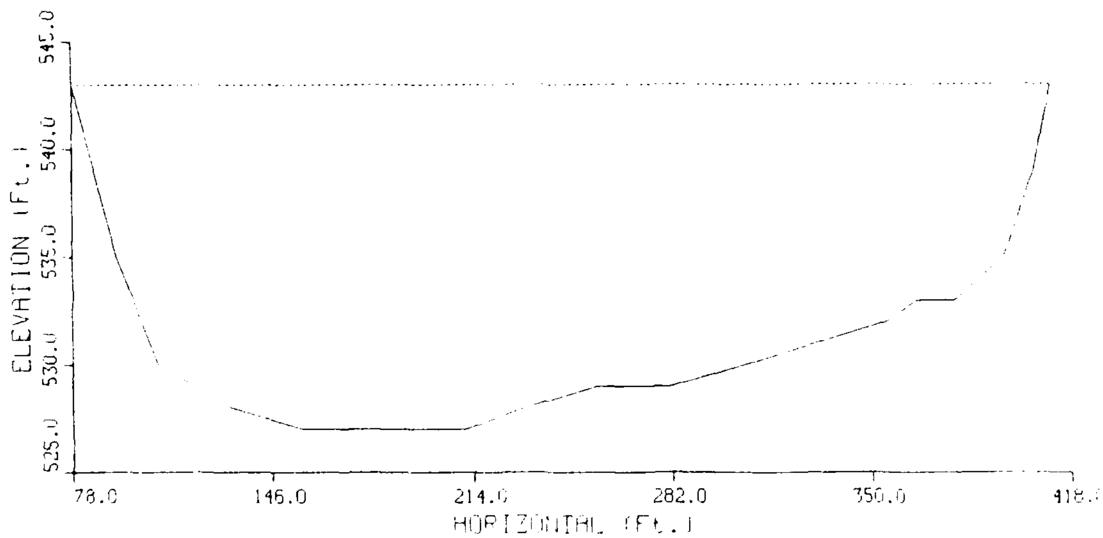


b. River

River Mile 447.35

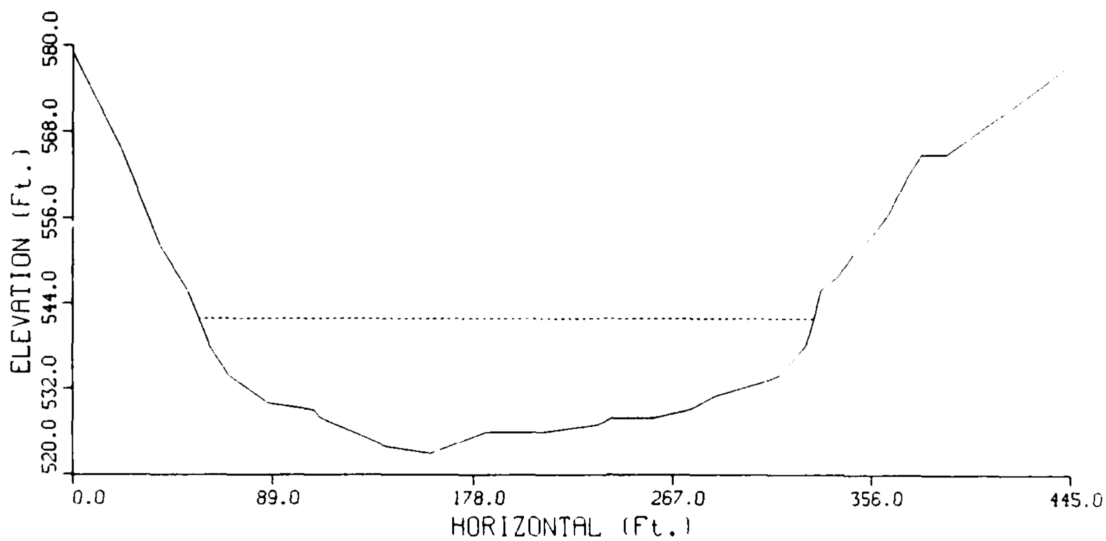


a. Whole valley

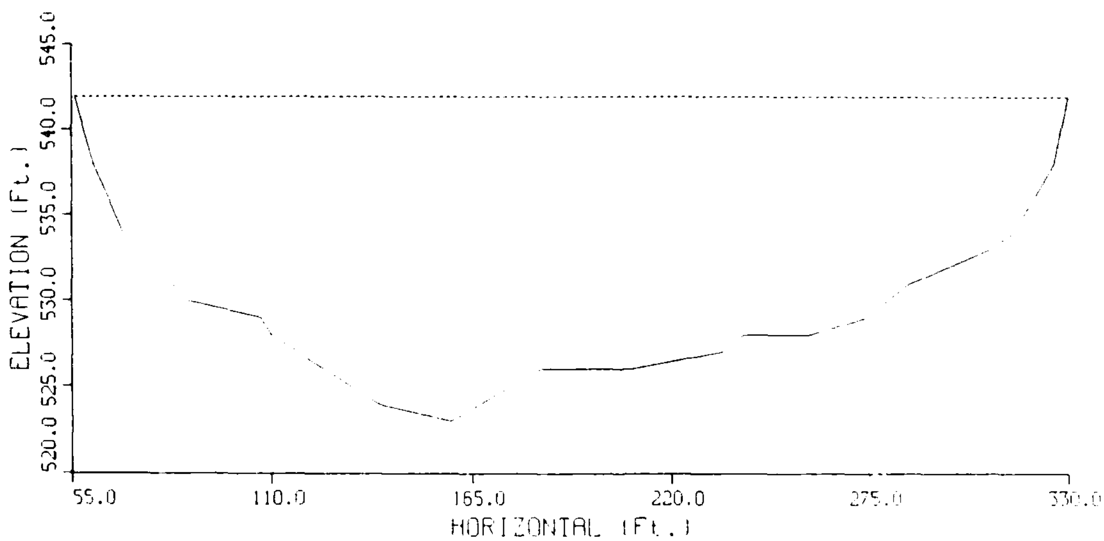


b. River

River Mile 446.99

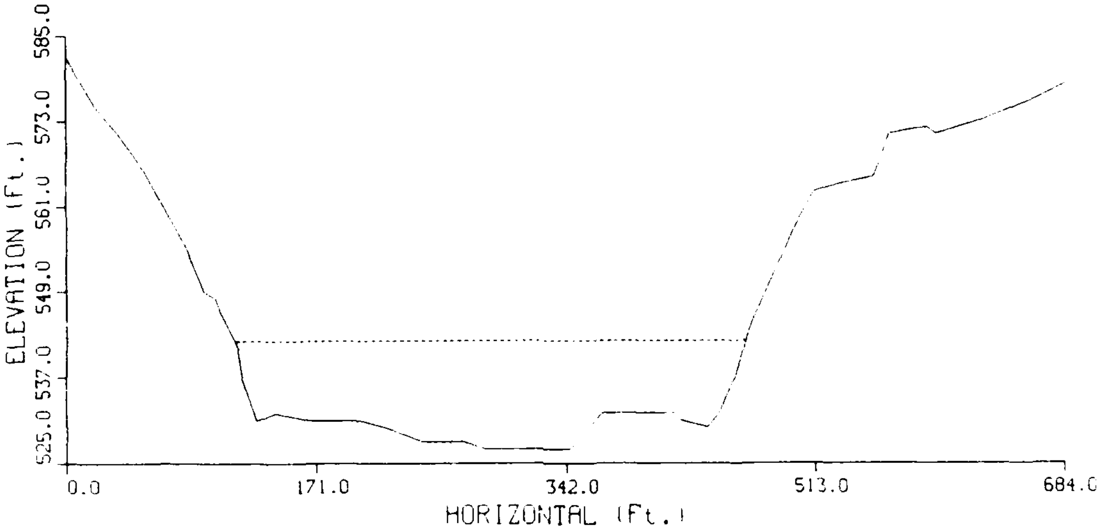


a. Whole valley

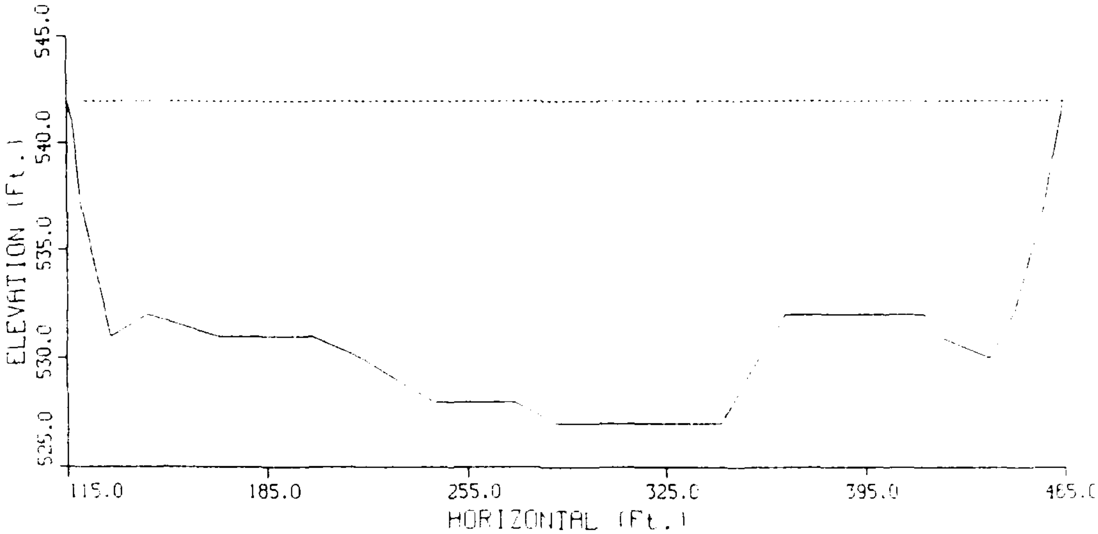


b. River

River Mile 445.38

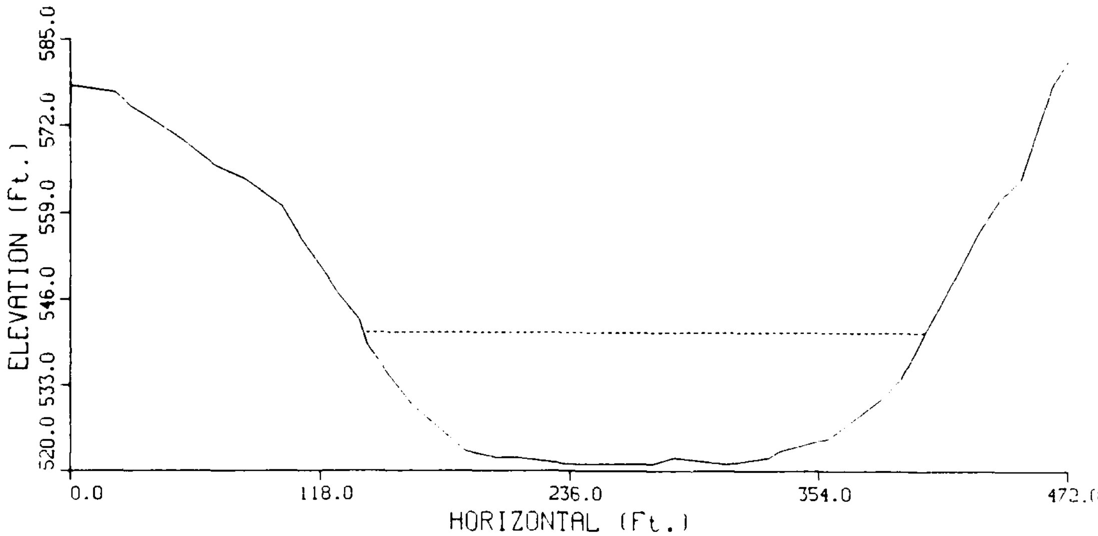


a. Whole valley

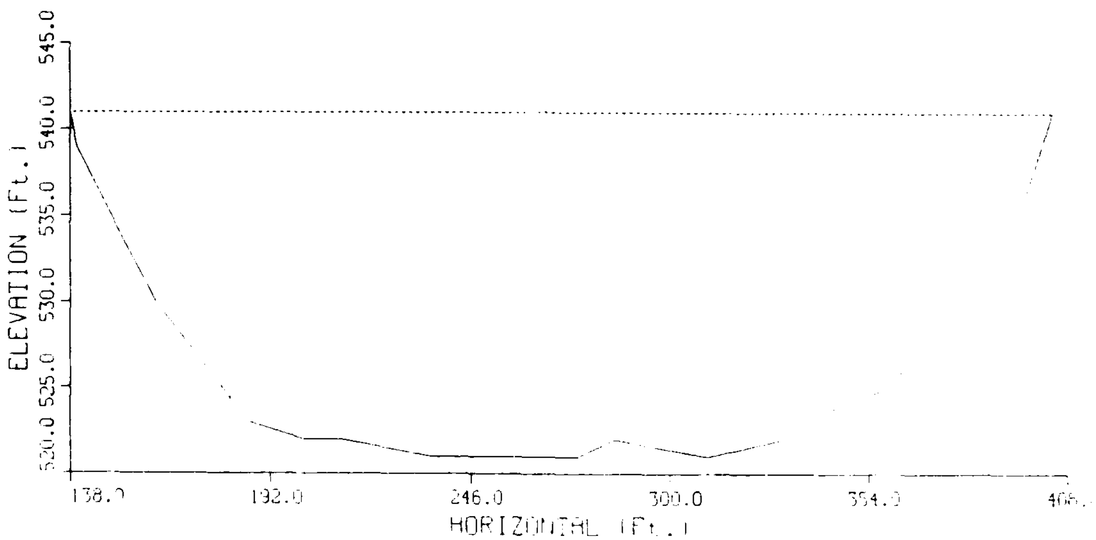


b. River

River Mile 444.79



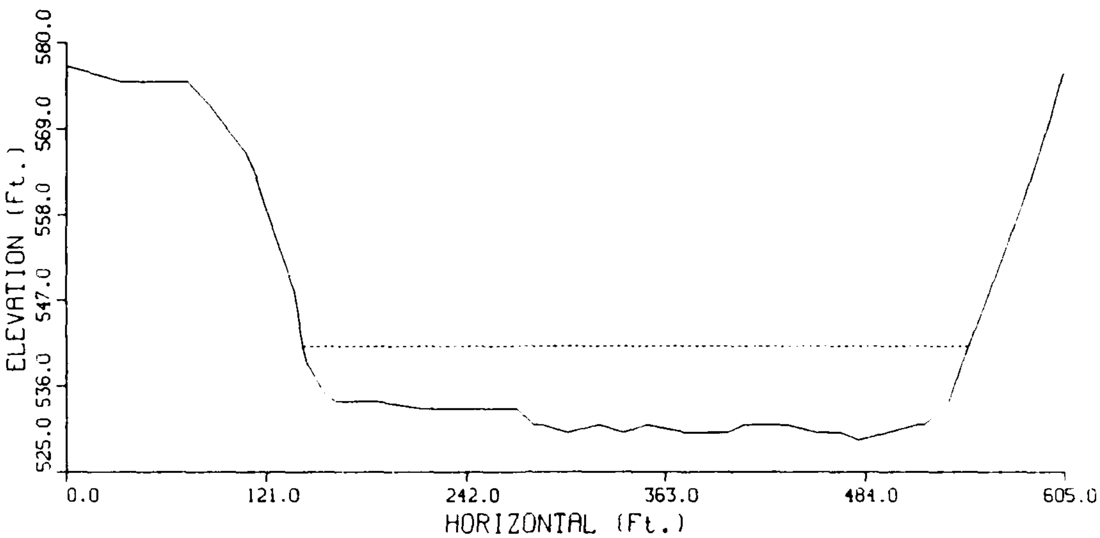
a. Whole valley



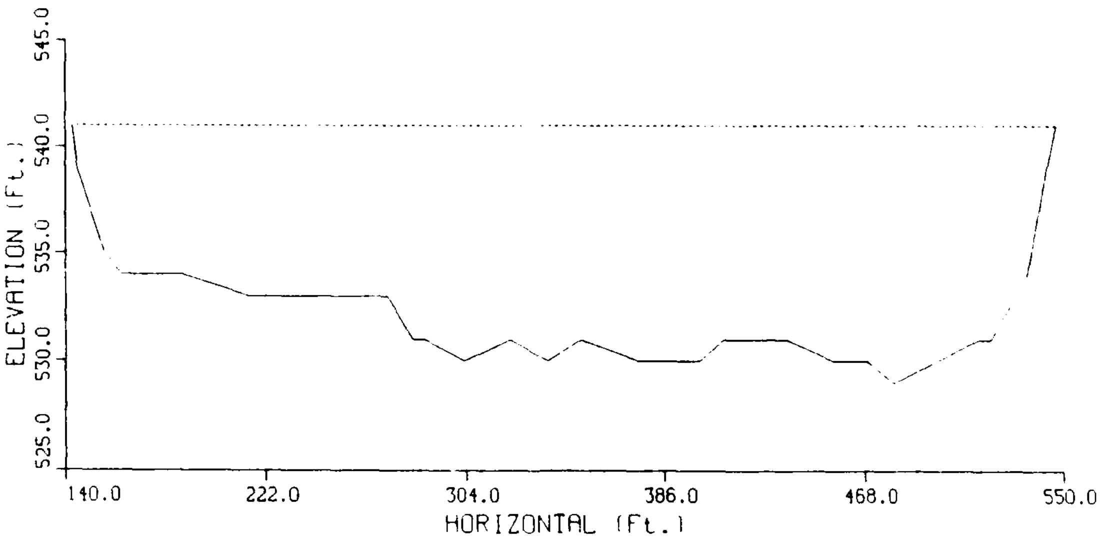
b. River

River Mile 443.78

AD-A200 562 PREDICTED EFFECTS OF HYDROPOWER UPRATE ON TROUT HABITAT 2/2
IN THE CUMBERLAND..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS ENVIR..
UNCLASSIFIED J M NESTLER ET AL. AUG 88 WES/MP/EL-88-10 F/G 13/2 NL

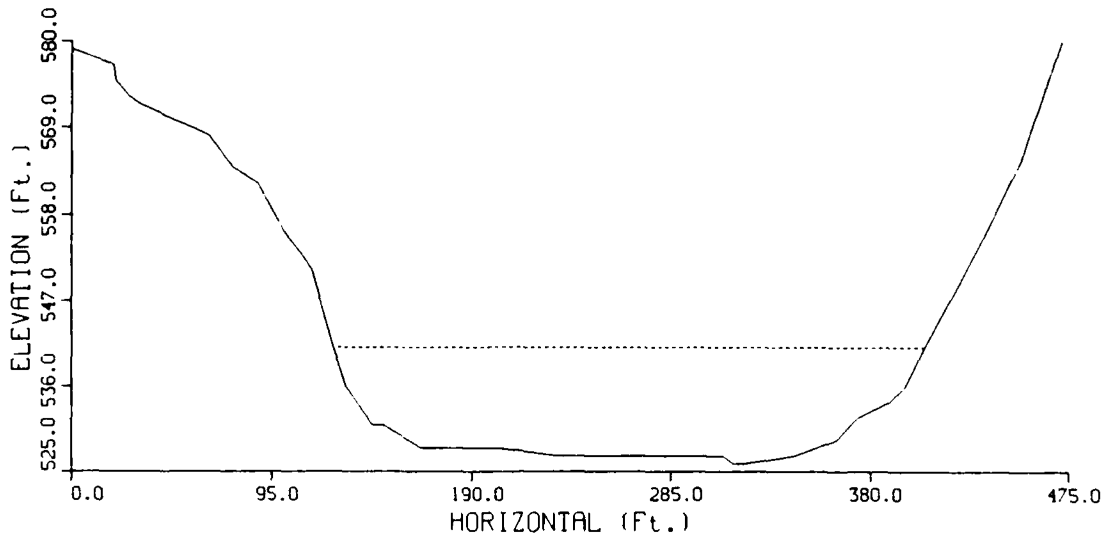


a. Whole valley

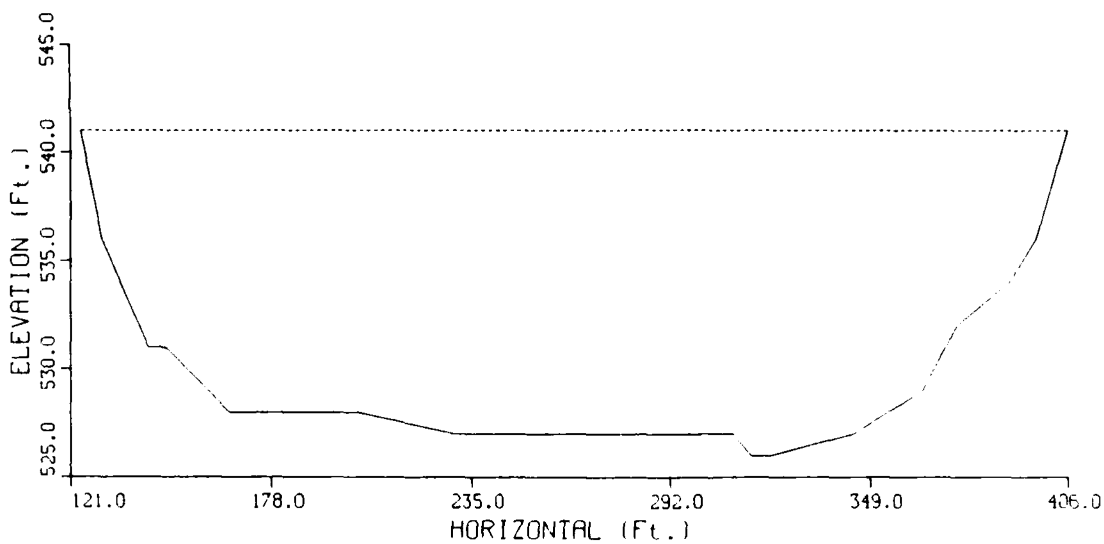


b. River

River Mile 443.38

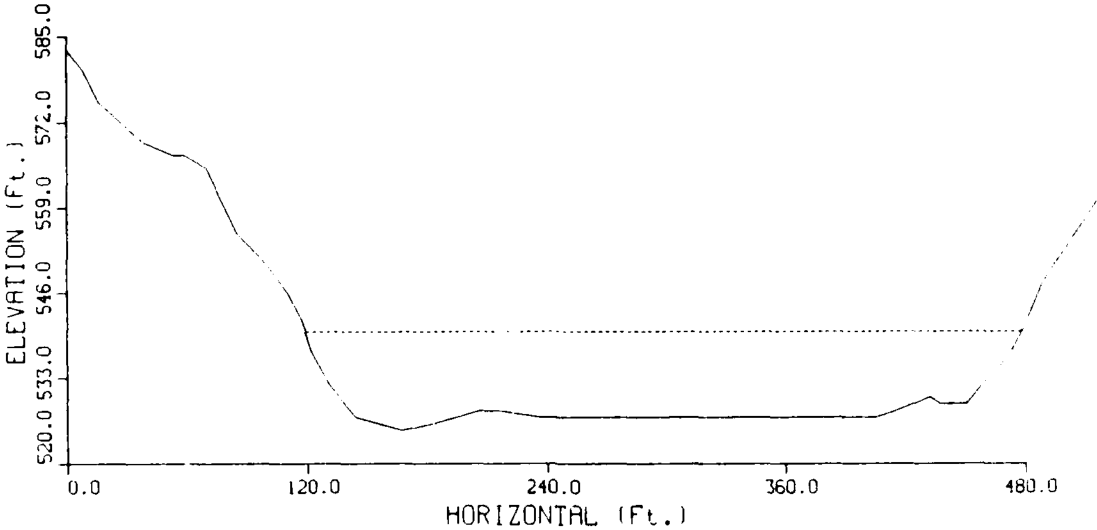


a. Whole valley

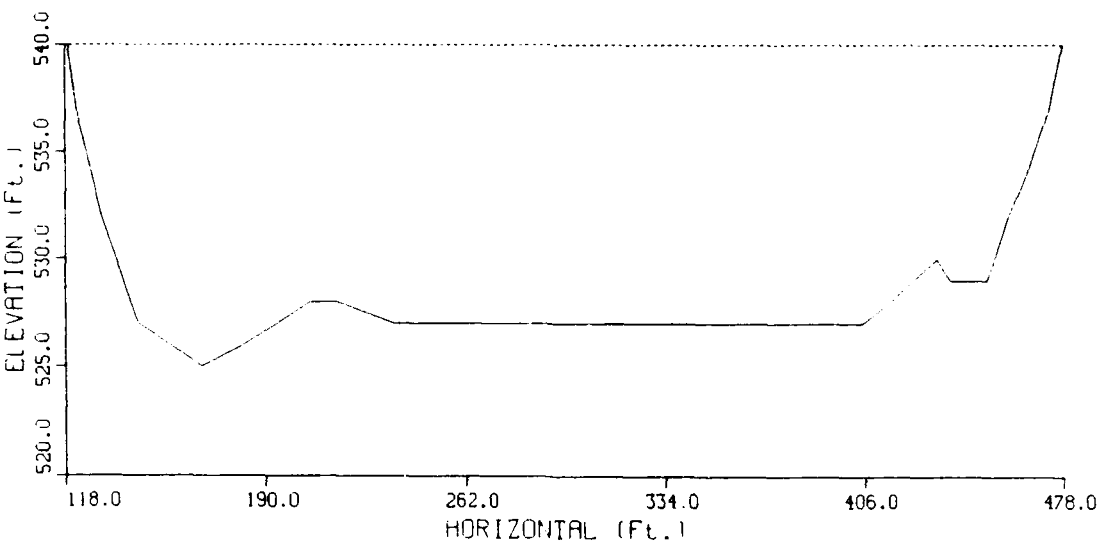


b. River

River Mile 443.04

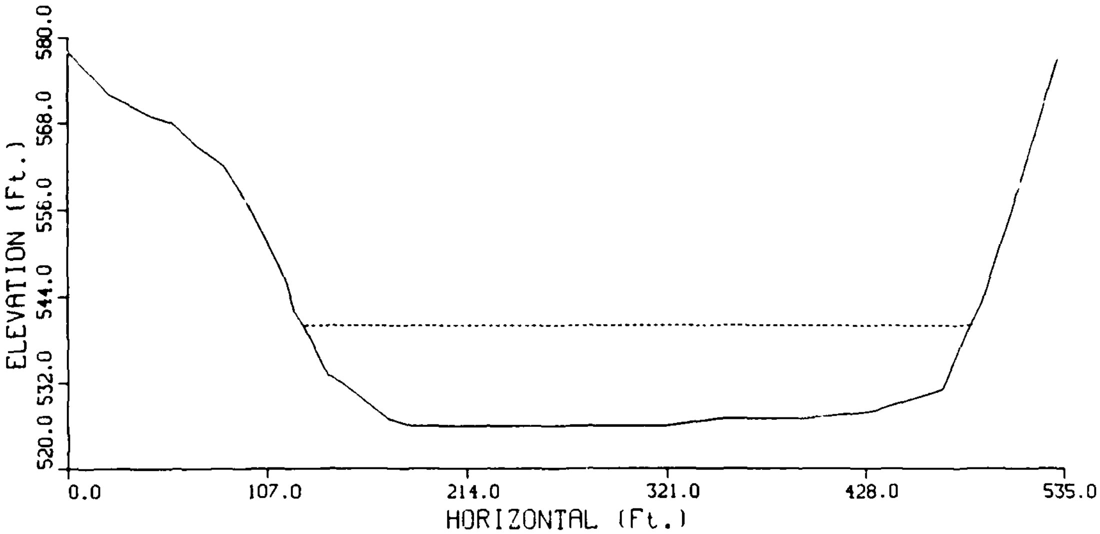


a. Whole valley

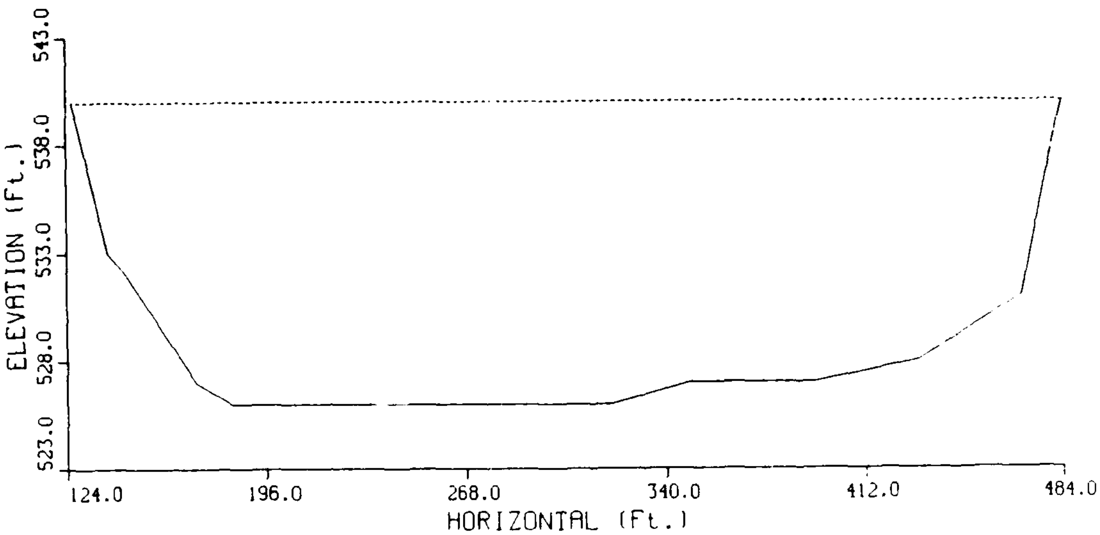


b. River

River Mile 442.16

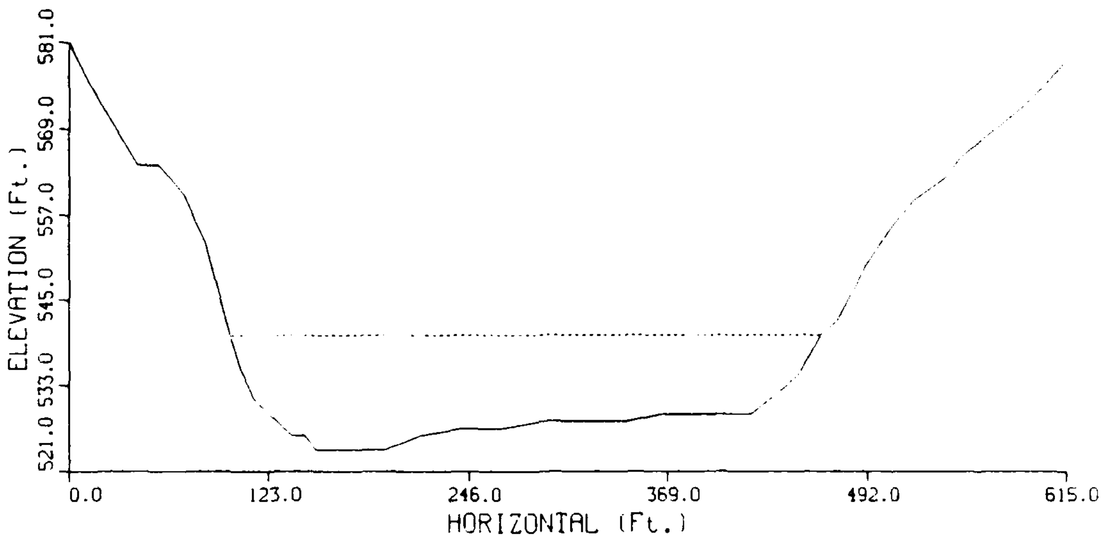


a. Whole valley

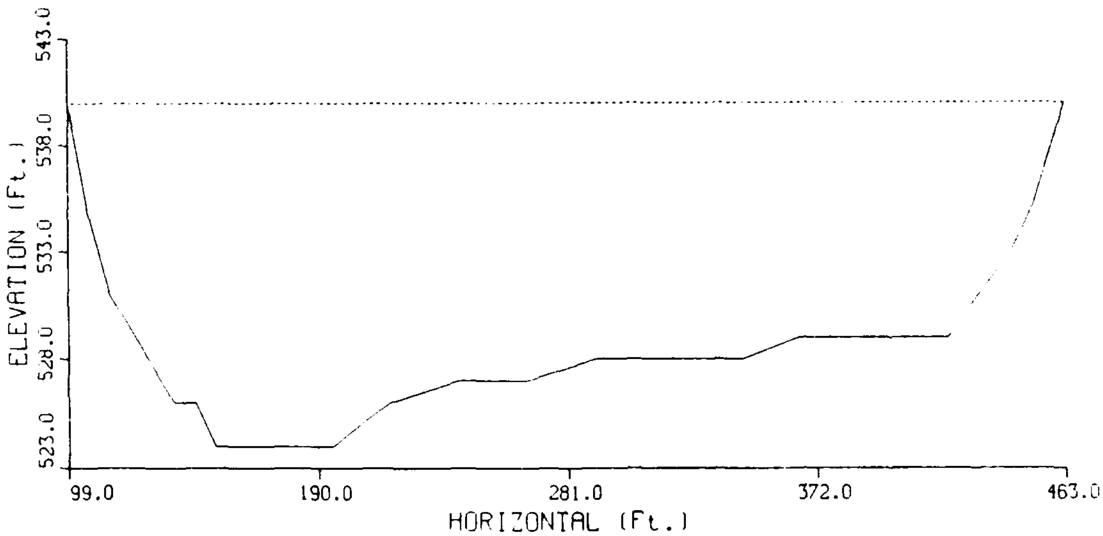


b. River

River Mile 441.02

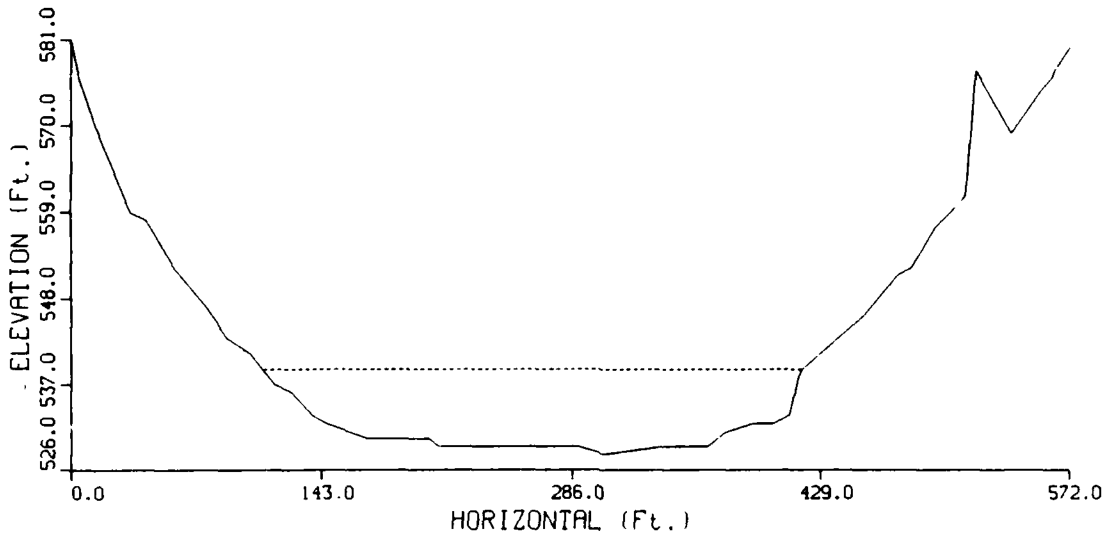


a. Whole valley

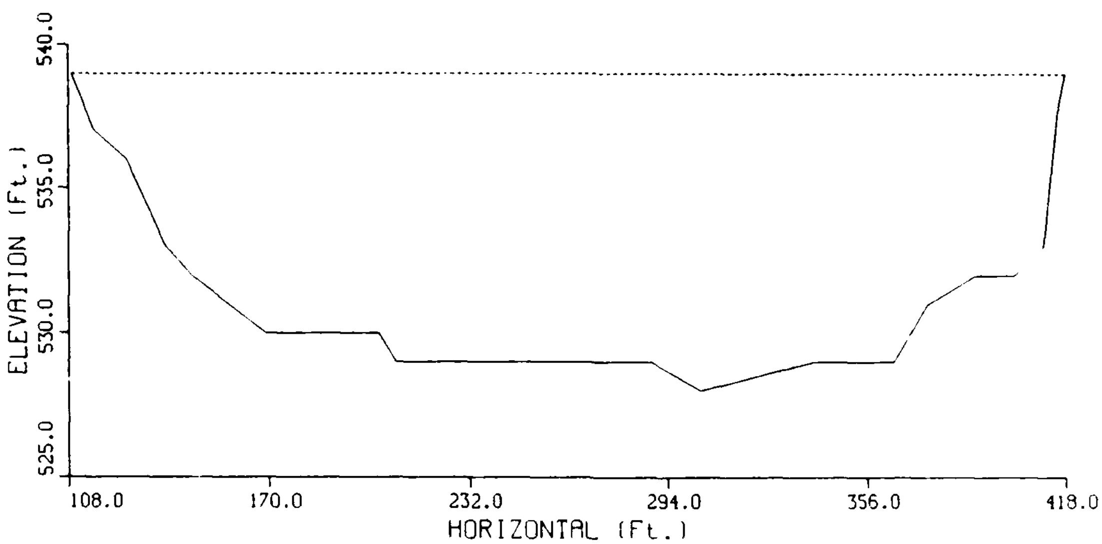


b. River

River Mile 440.25

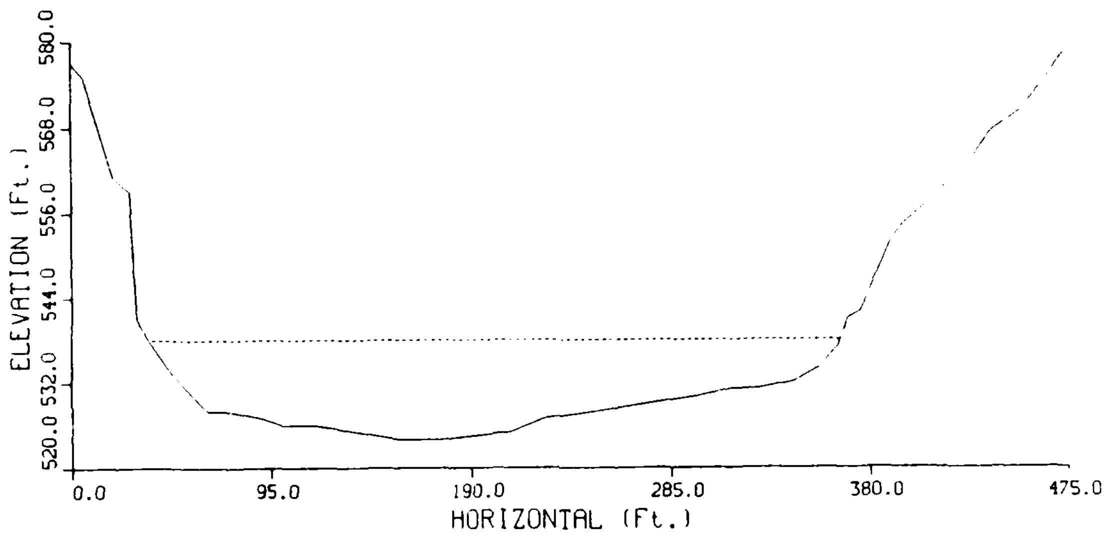


a. Whole valley

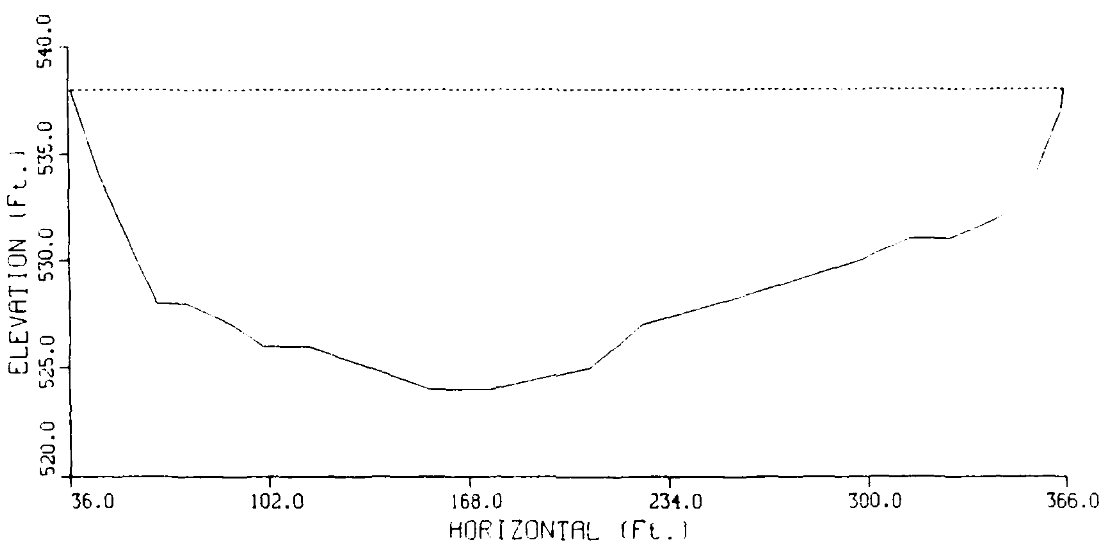


b. River

River Mile 439.94

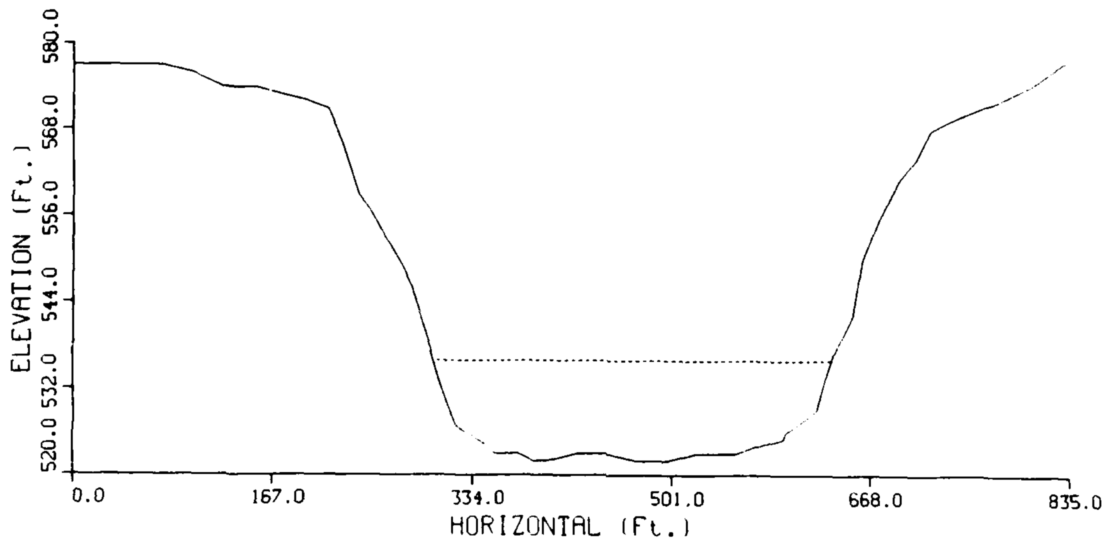


a. Whole valley

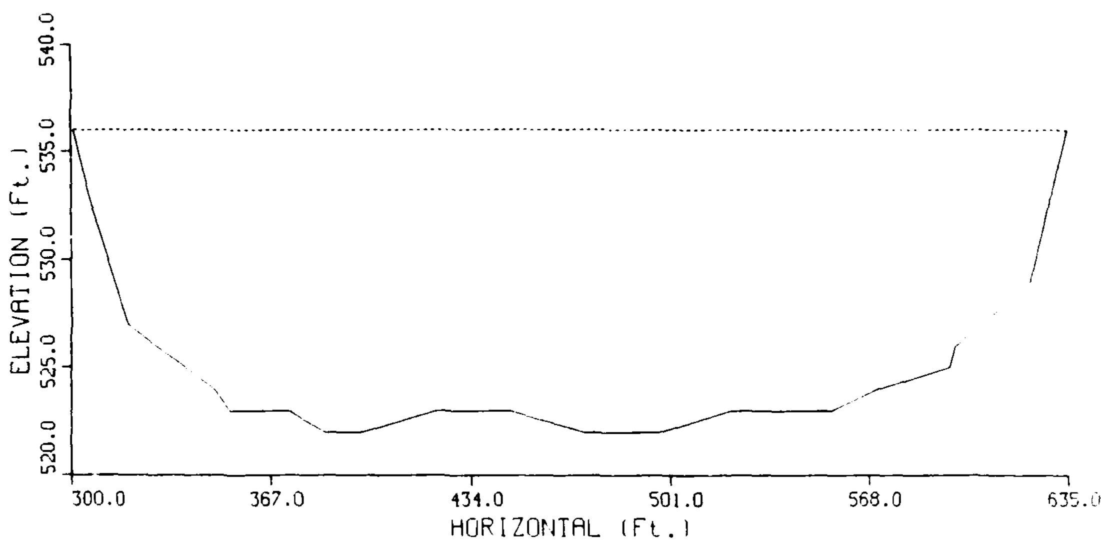


b. River

River Mile 438.88

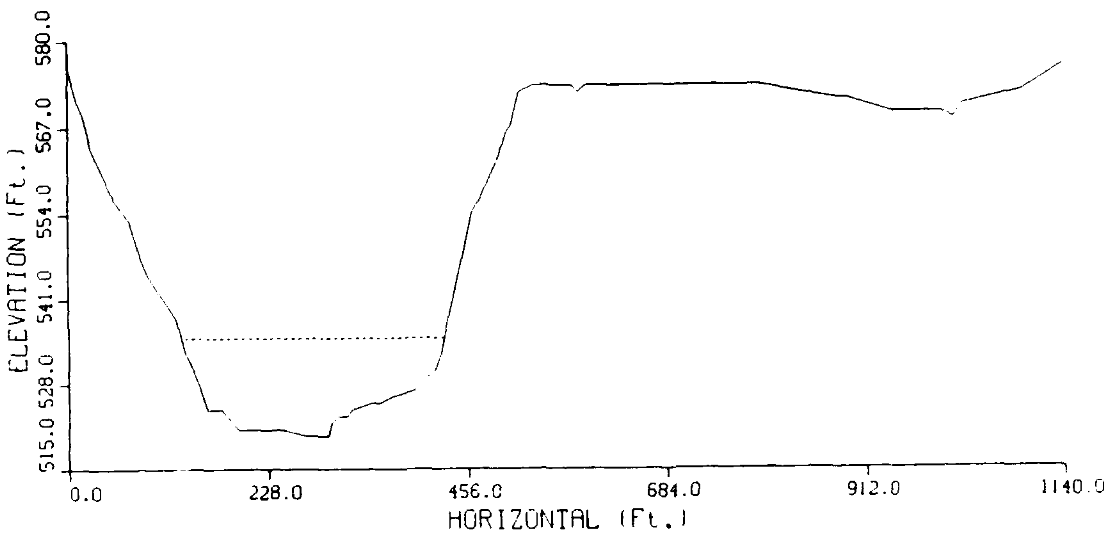


a. Whole valley

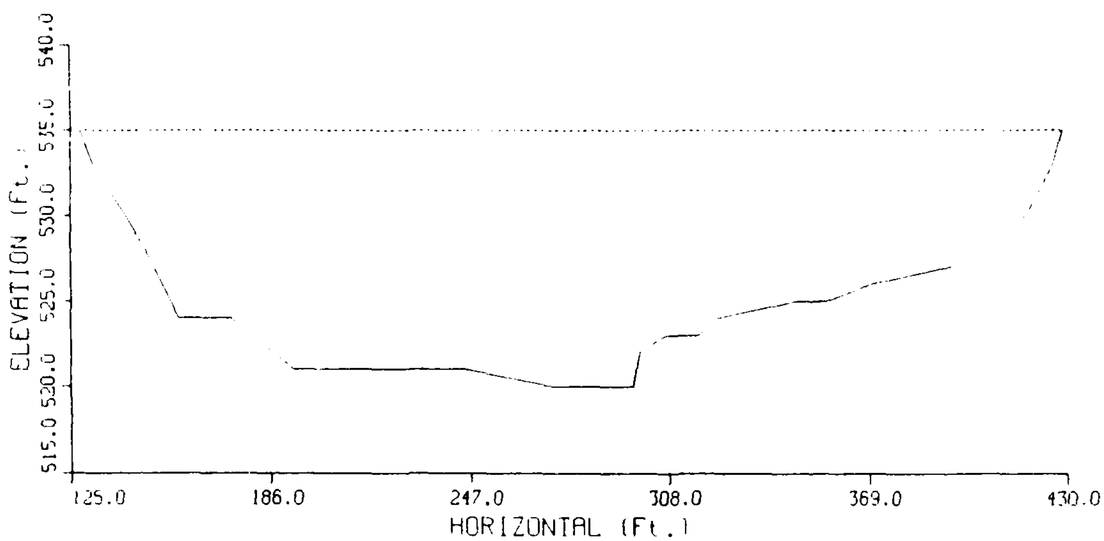


b. River

River Mile 437.34

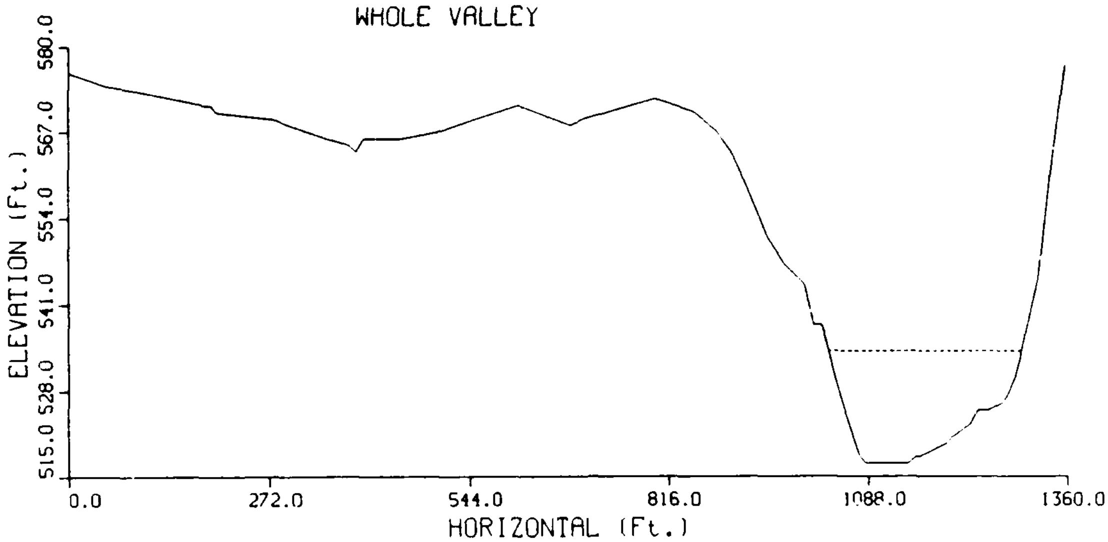


a. Whole valley

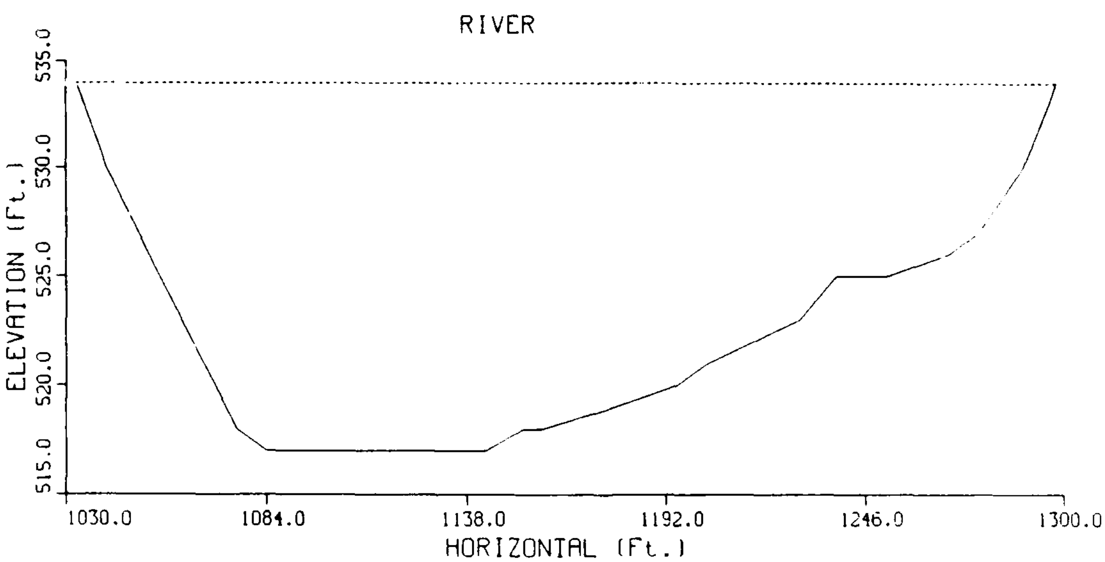


b. River

River Mile 435.43

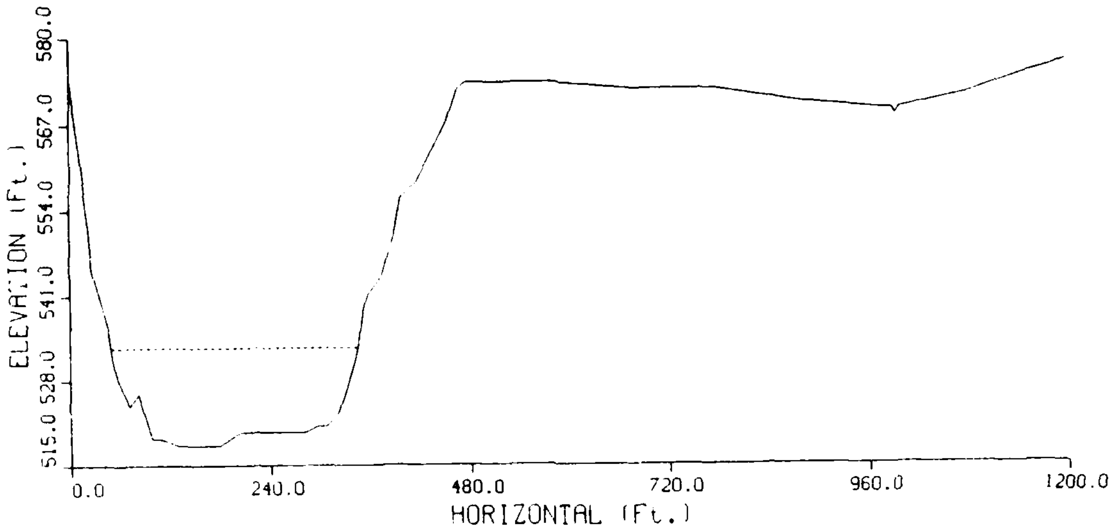


a. **Whole valley**

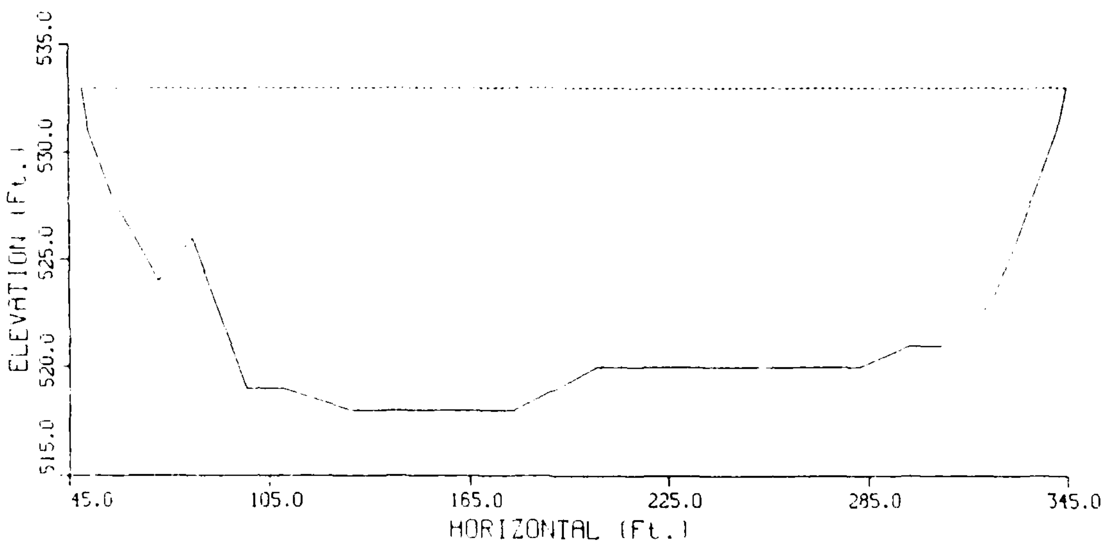


b. River

River Mile 433.64

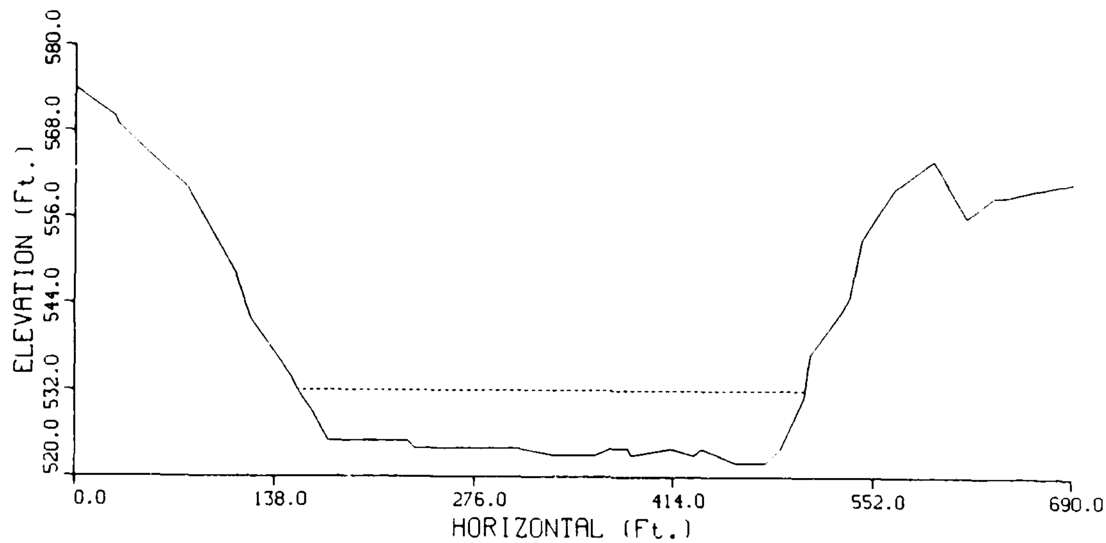


a. Whole valley

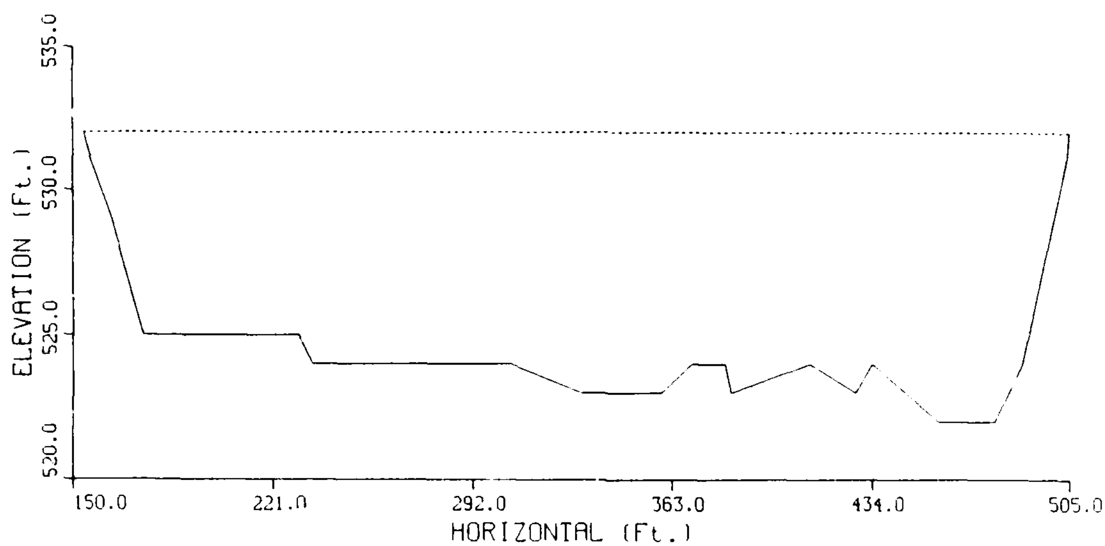


b. River

River Mile 432.50

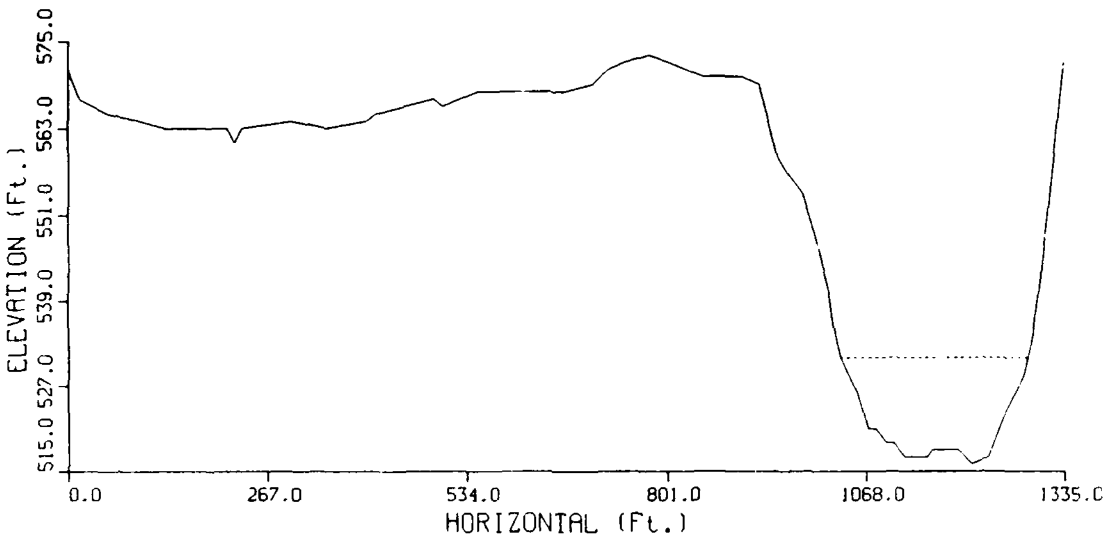


a. Whole valley

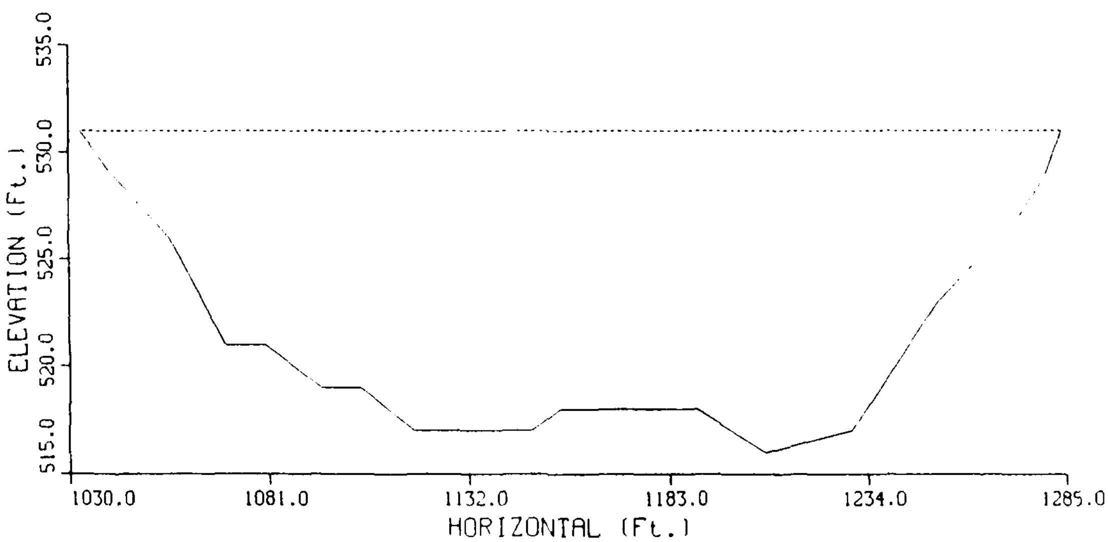


b. River

River Mile 431.42

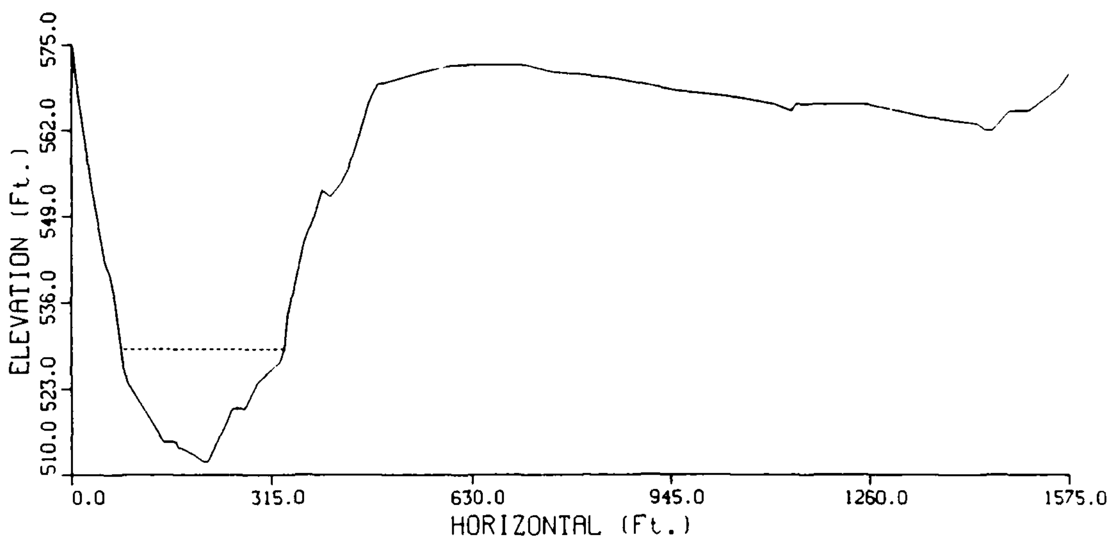


a. Whole valley

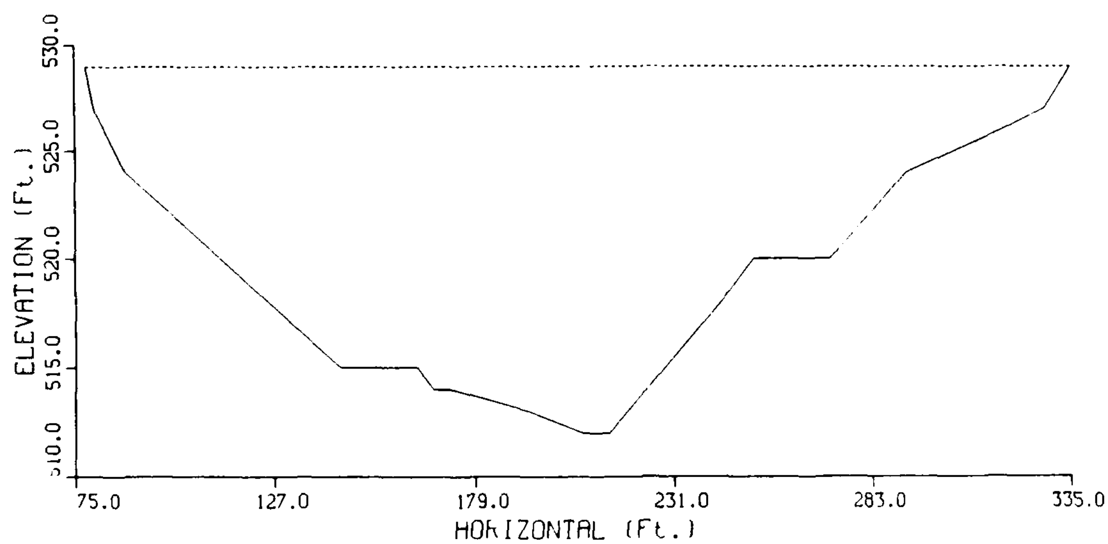


b. River

River Mile 430.41

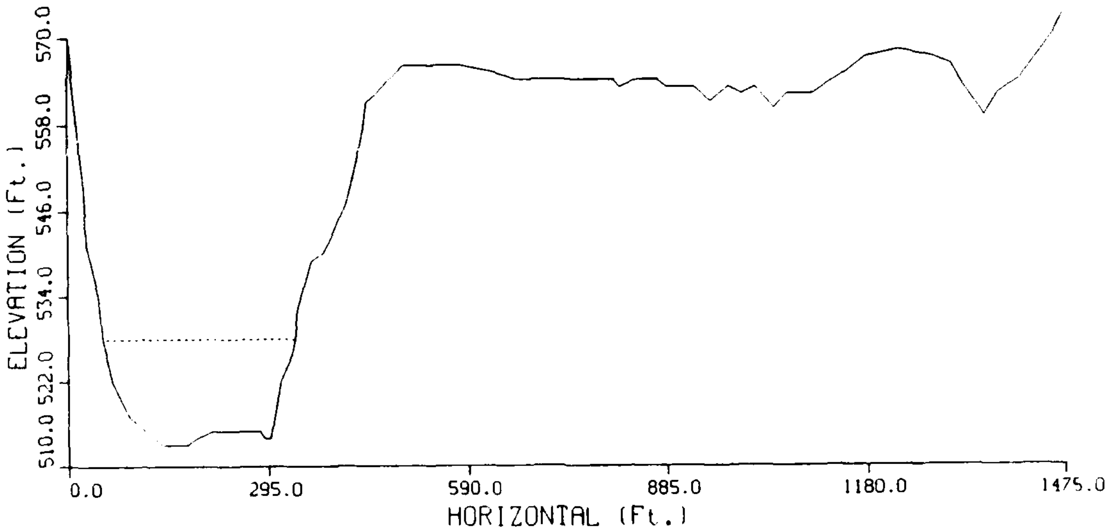


a. Whole valley

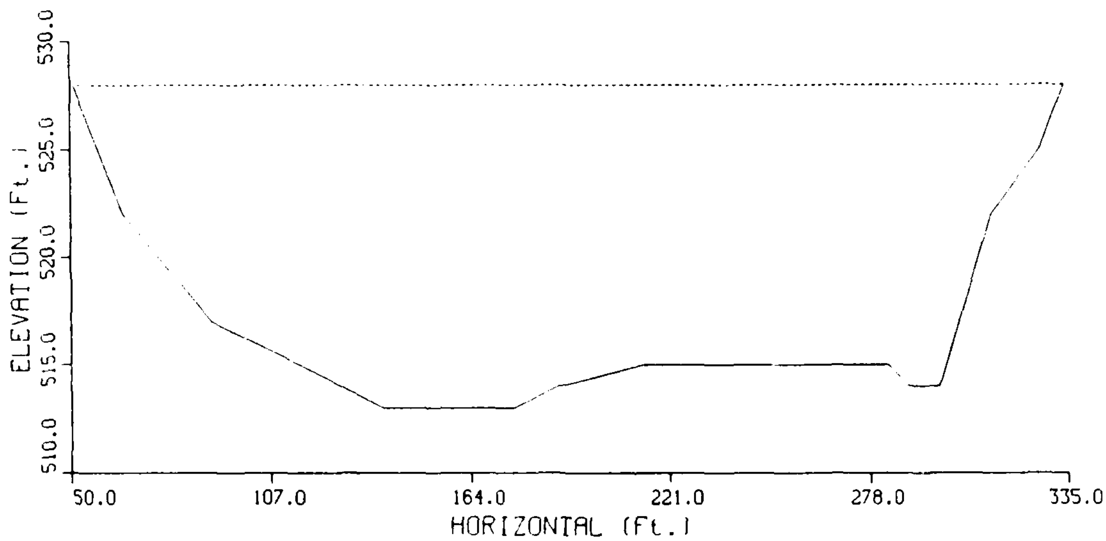


b. River

River Mile 428.64



a. Whole valley



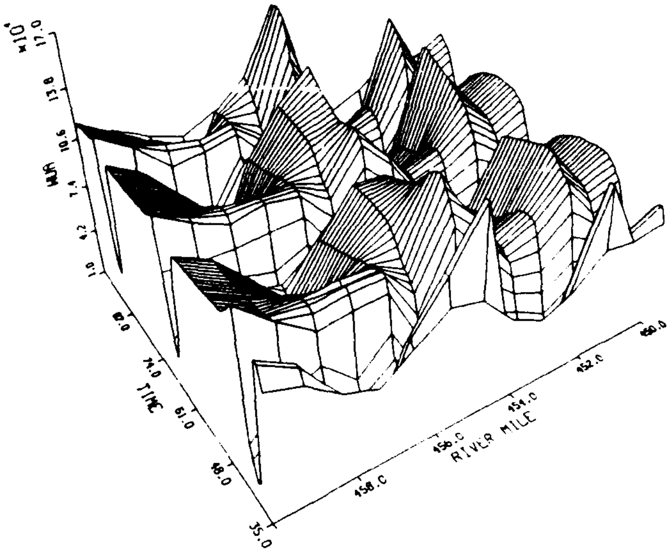
b. River

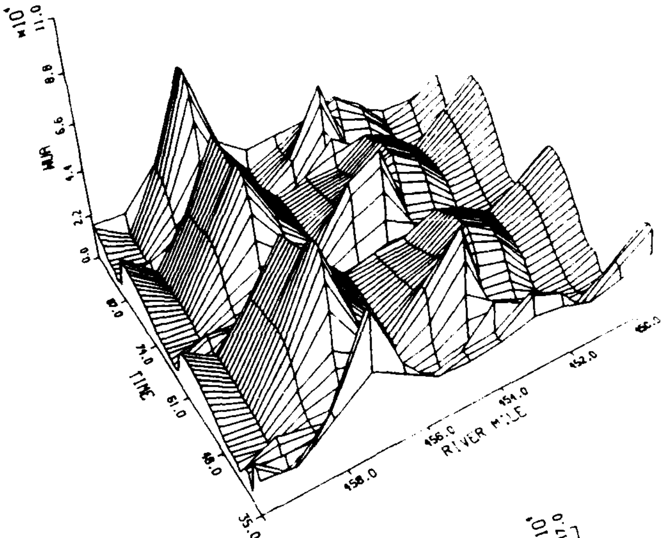
River Mile 427.8

APPENDIX D: THREE-DIMENSIONAL PLOTS OF WUA/1,000 FT VERSUS TIME AND DOWNSTREAM DISTANCE (RIVER MILE)

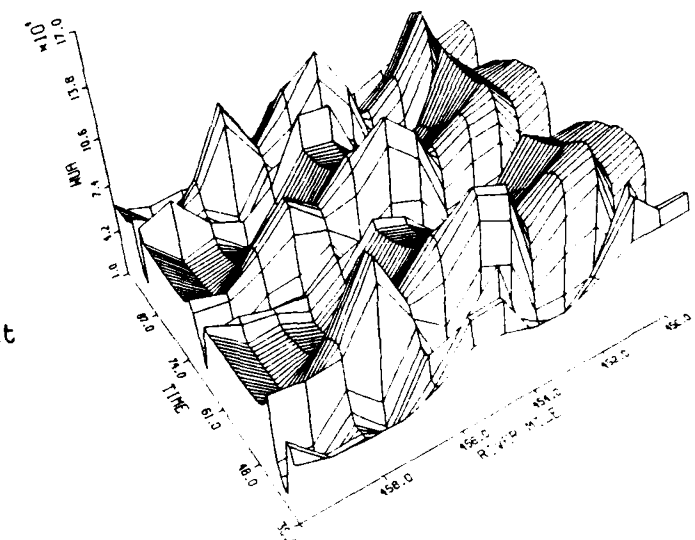
(For purposes of cross reference, stage-discharge information is available in Appendix B for each release schedule and for each hydrologic condition. The following plots are grouped by river reach as follows: most of upstream reach, pages D3 to D8; middle reach, pages D9 to D14; and most of downstream reach, pages D15 to D20. Within each river reach, plots are further subsetted--first by release schedule (existing versus uprate), then by hydrologic condition, and finally by life stage.)

Species = Adult Brown Trout



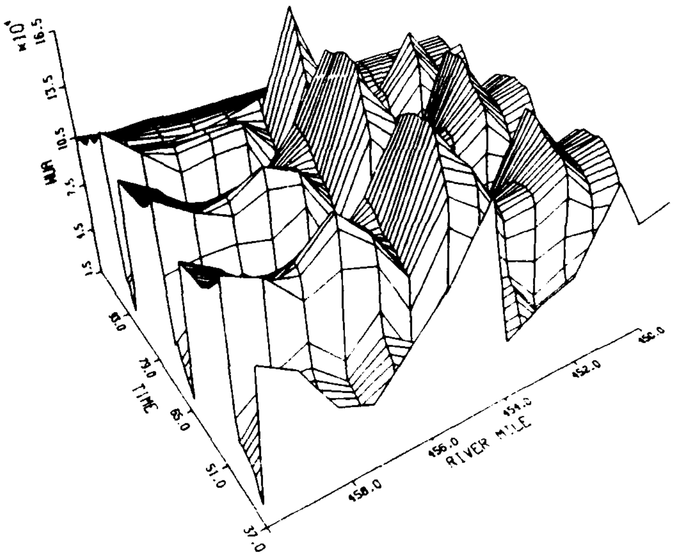


Species = Juvenile Brown Trout

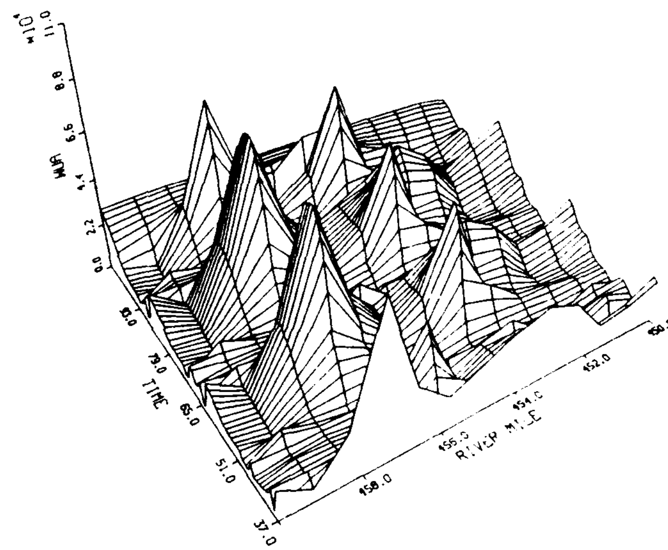


Species = Adult Rainbow Trout

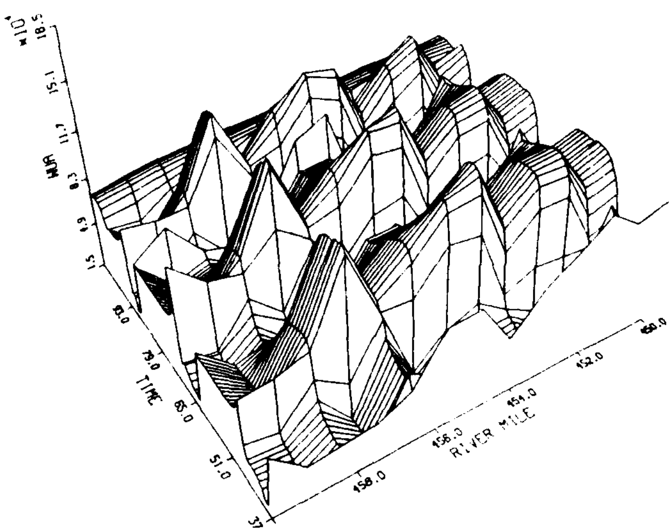
Cumberland River, September Existing Conditions



Species = Adult Brown Trout



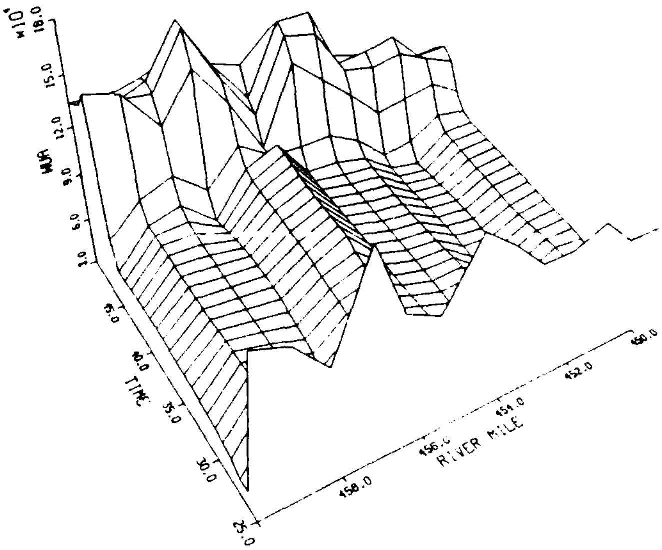
Species = Juvenile Brown Trout

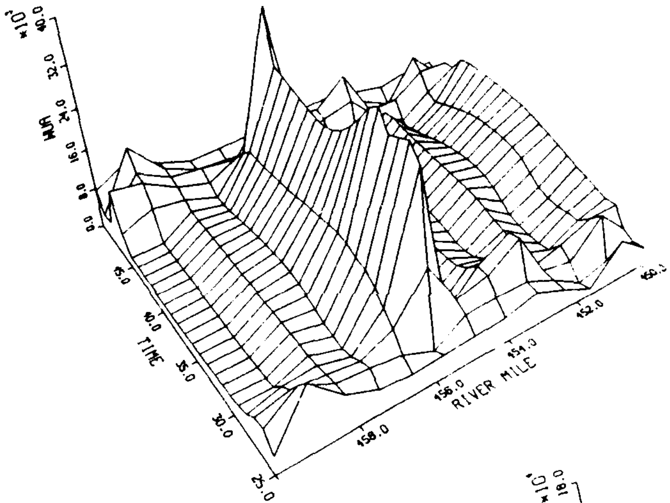


Species = Adult Rainbow Trout

Cumberland River, 50-Percent Existing Conditions

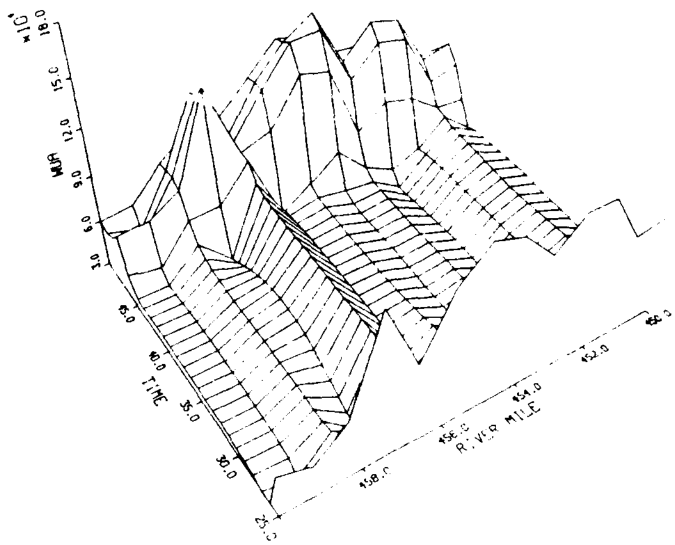
Species = Adult Brown Trout



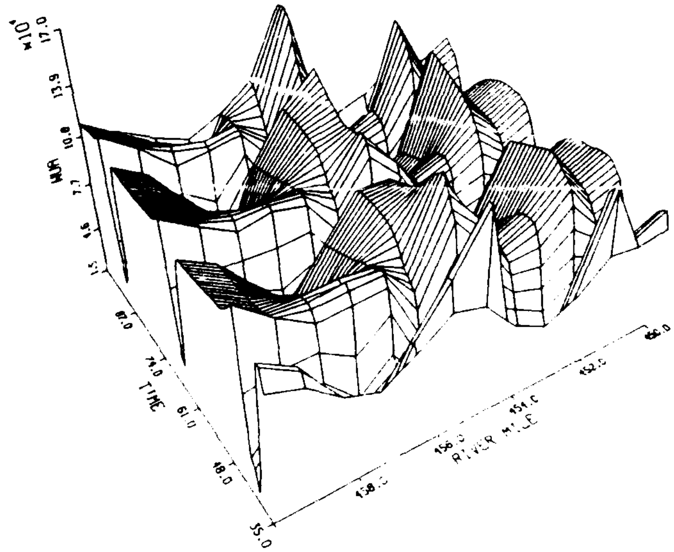


Species = Juvenile Brown Trout

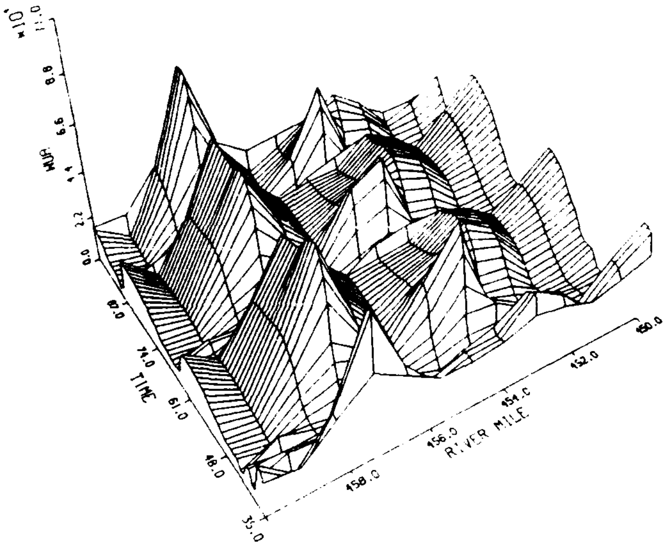
Species = Adult Rainbow Trout



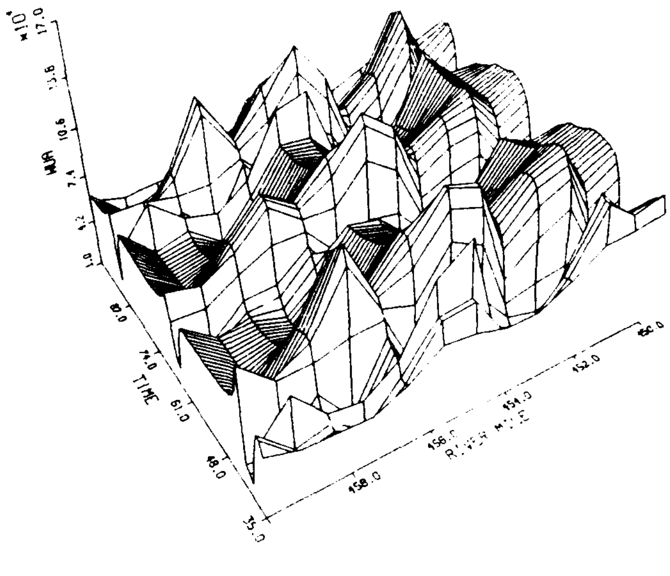
Cumberland River, 10-Percent Existing Conditions



Species = Adult Brown Trout



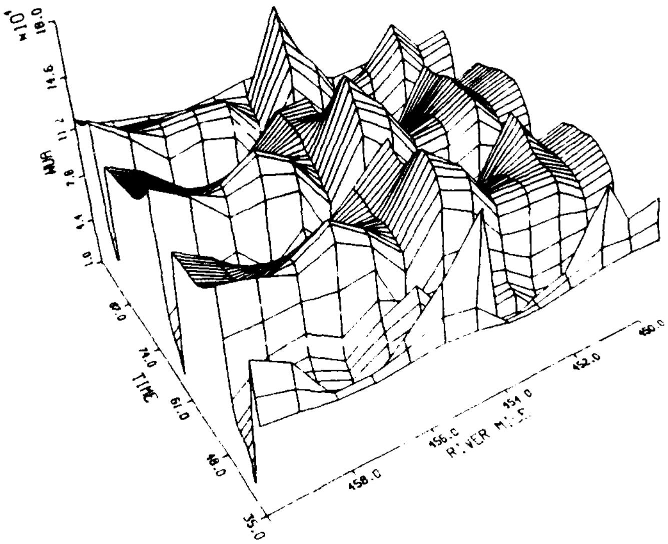
Species = Juvenile Brown Trout

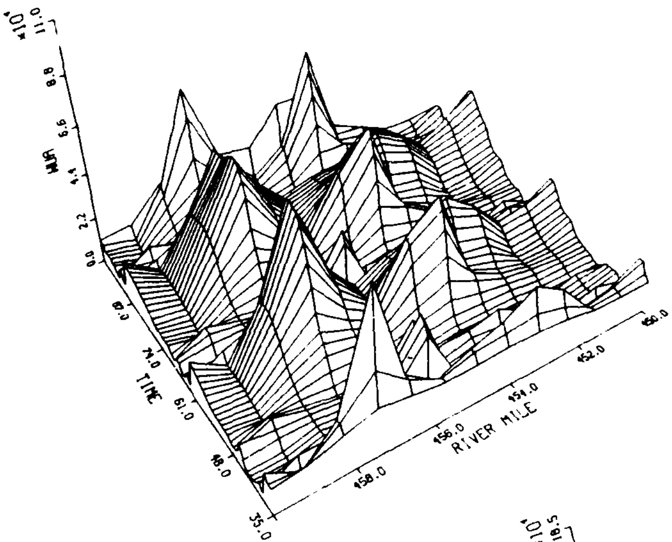


Species = Adult Rainbow Trout

Cumberland River, September Uprate Conditions

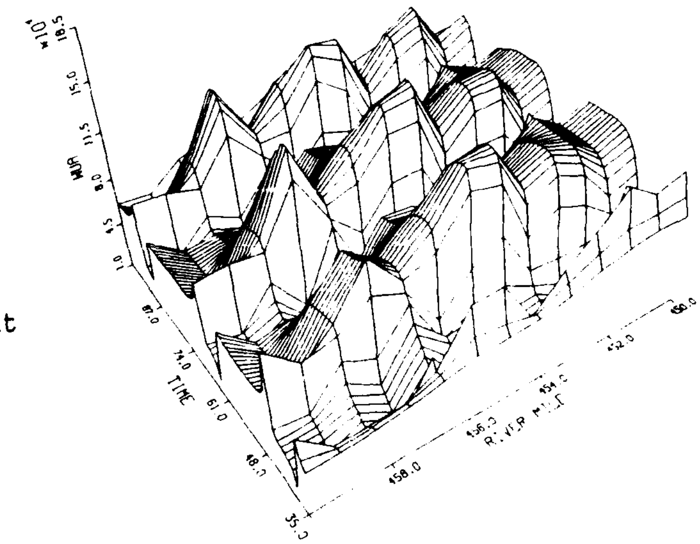
Species = Adult Brown Trout



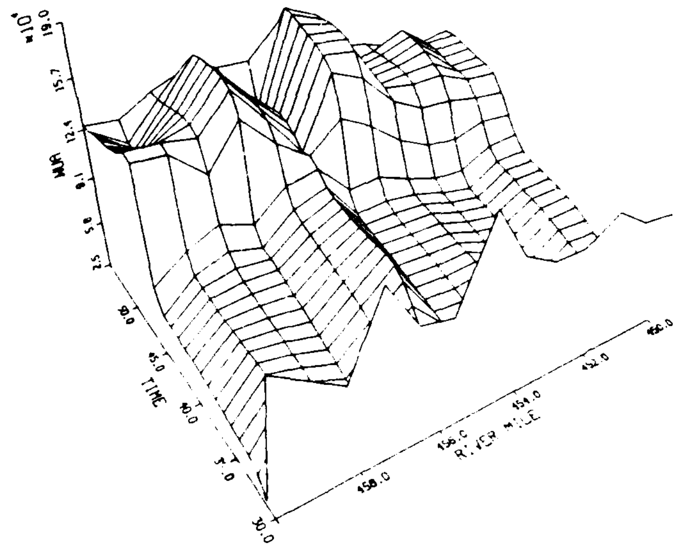


Species = Juvenile Brown Trout

Species = Adult Rainbow Trout

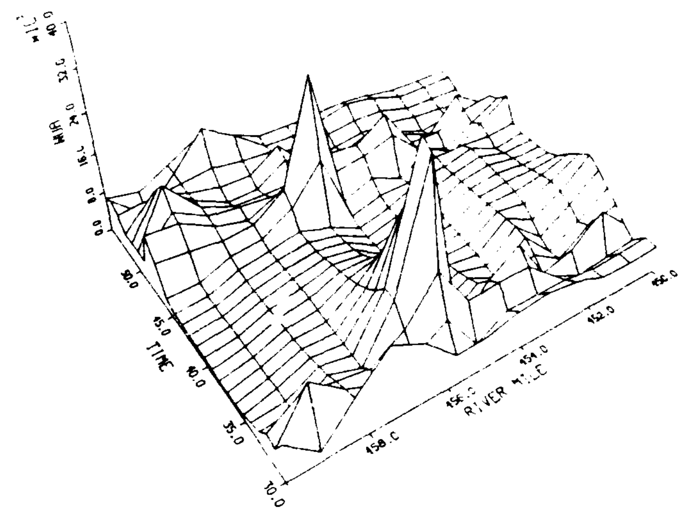


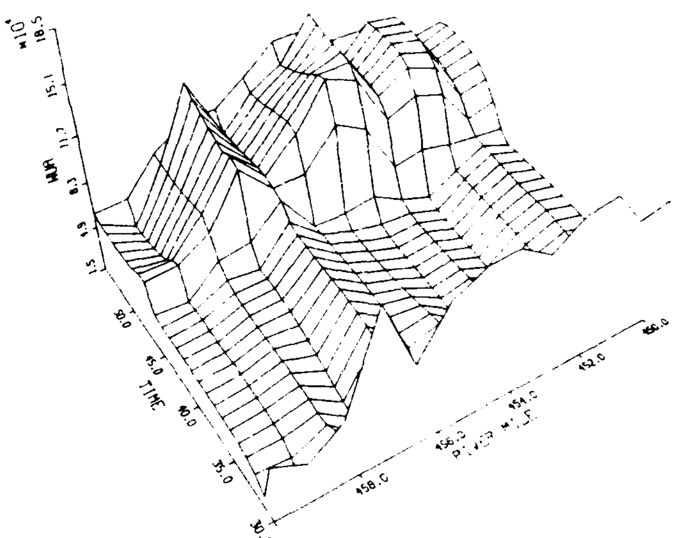
Cumberland River, 50-Percent Uprate Conditions



Species = Adult Brown Trout

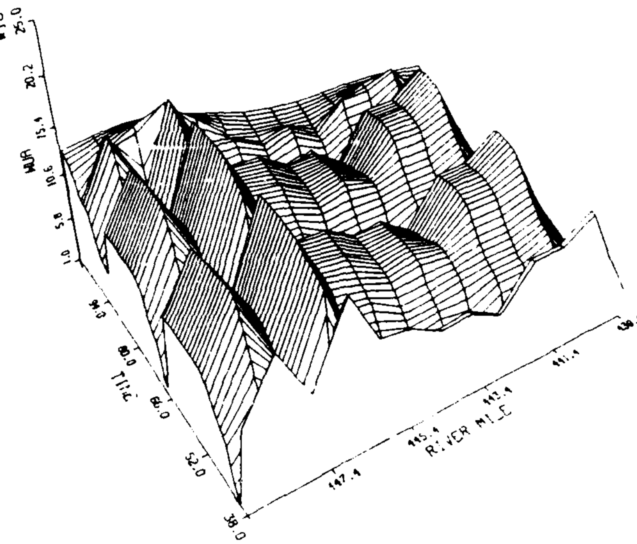
Species = Juvenile Brown Trout



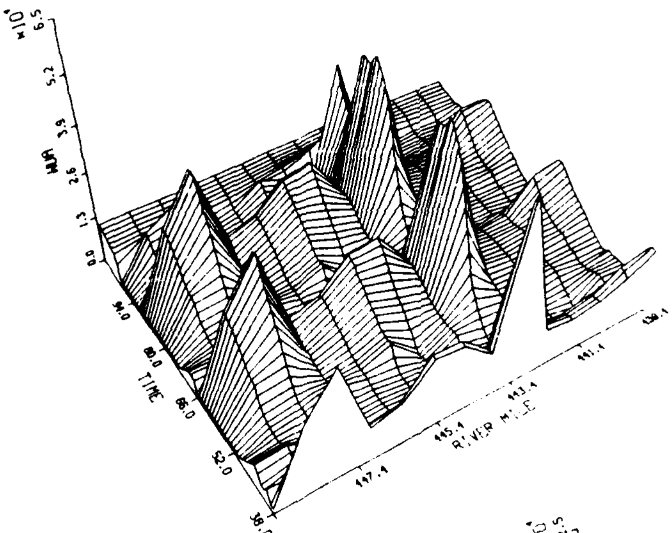


Species = Adult Rainbow Trout

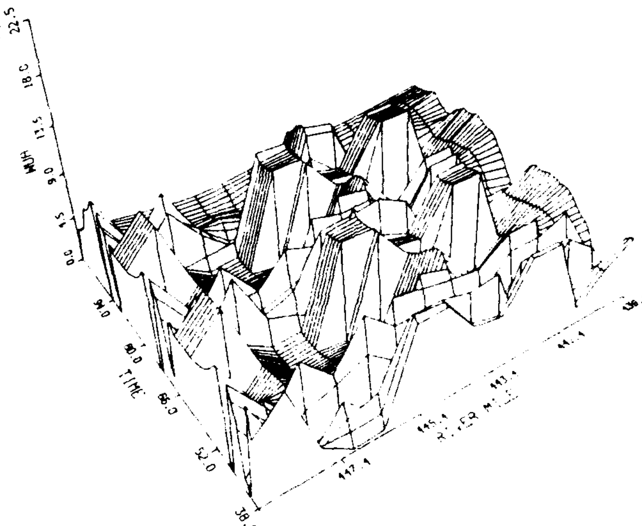
Cumberland River, 10-Percent Uprate Conditions



Species = Adult Brown Trout

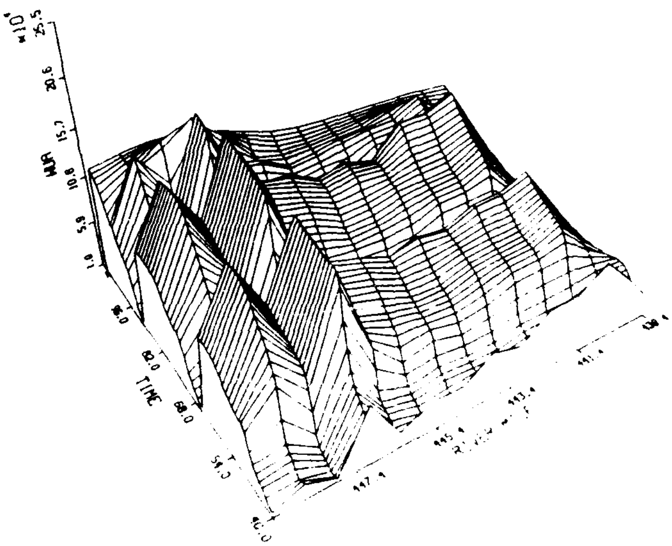


Species = Juvenile Brown Trout

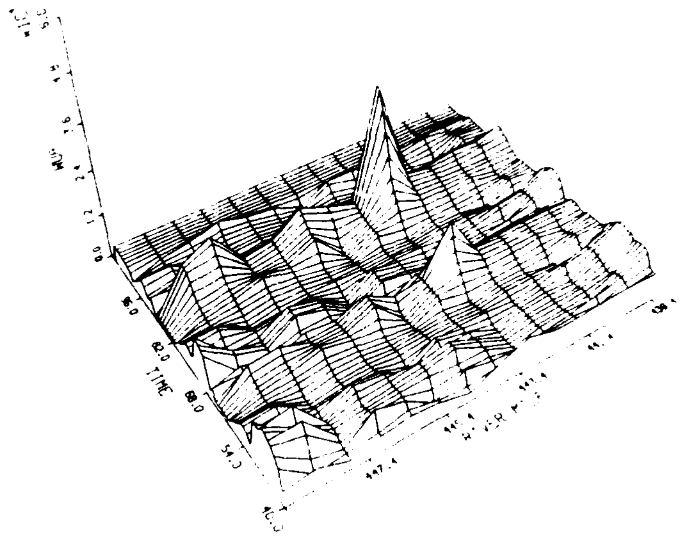


Species = Adult Rainbow Trout

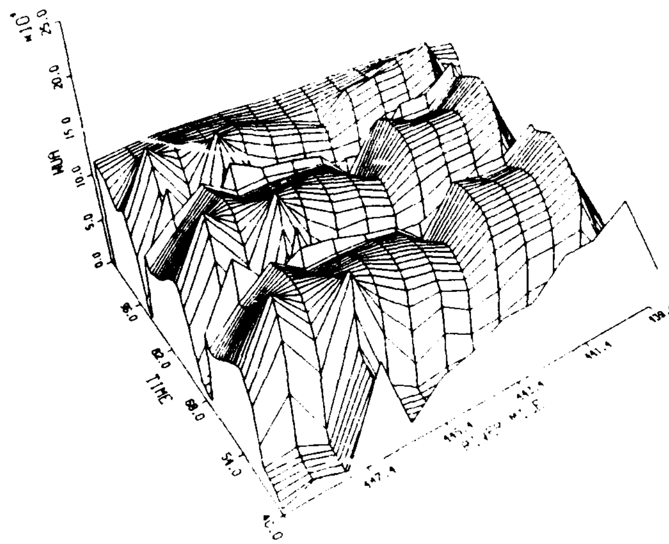
Cumberland River, September Existing Conditions



Species = Adult Brown Trout



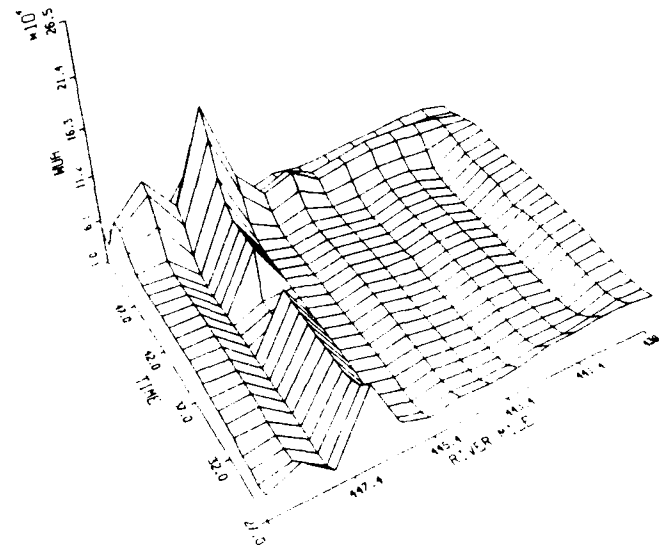
Species = Juvenile Brown Trout



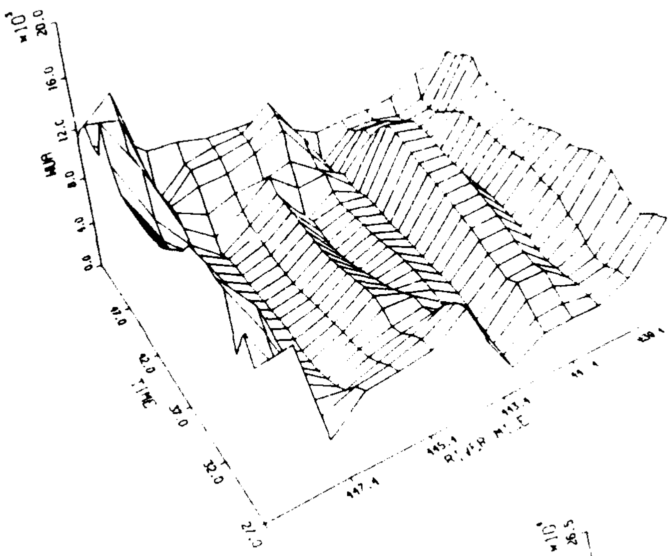
Species = Adult Rainbow Trout

Cumberland River, 50-Percent Existing Conditions

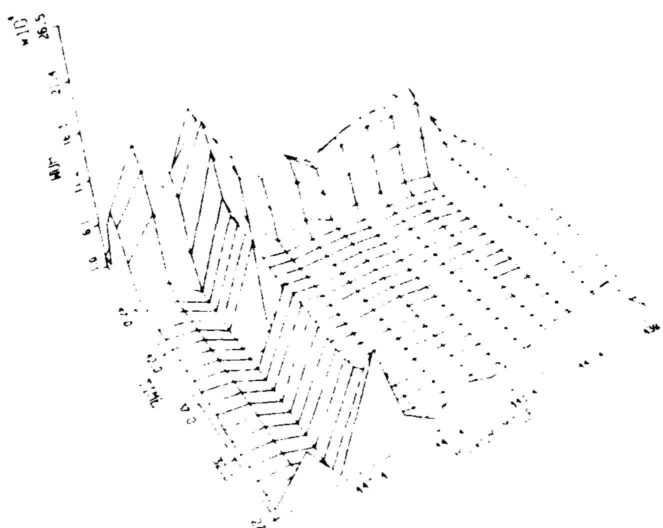
Species = Adult Brown Trout



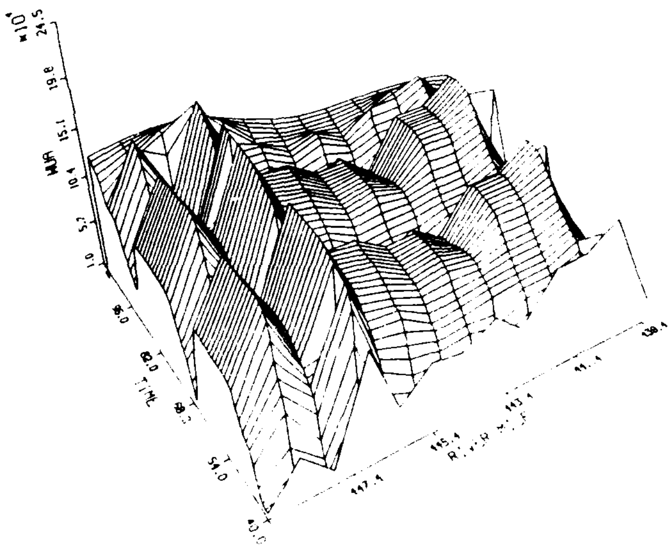
Species = Juvenile Brown Trout



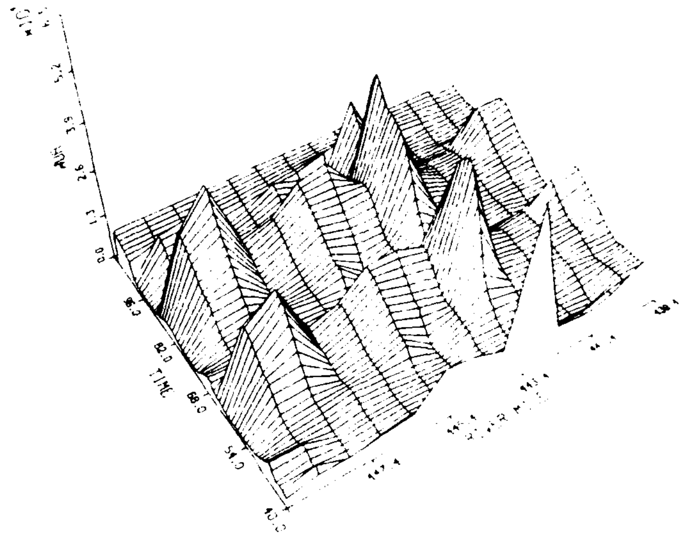
Species = Adult Rainbow Trout



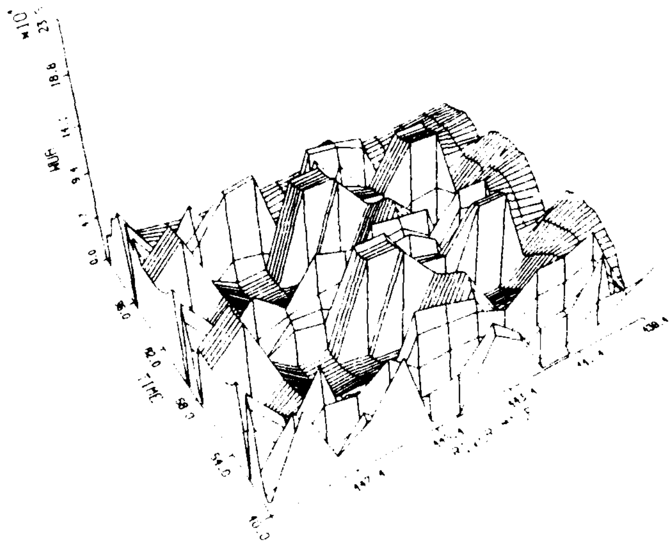
Cumberland River, 10-Percent Existing Conditions



Species = Adult Brown Trout



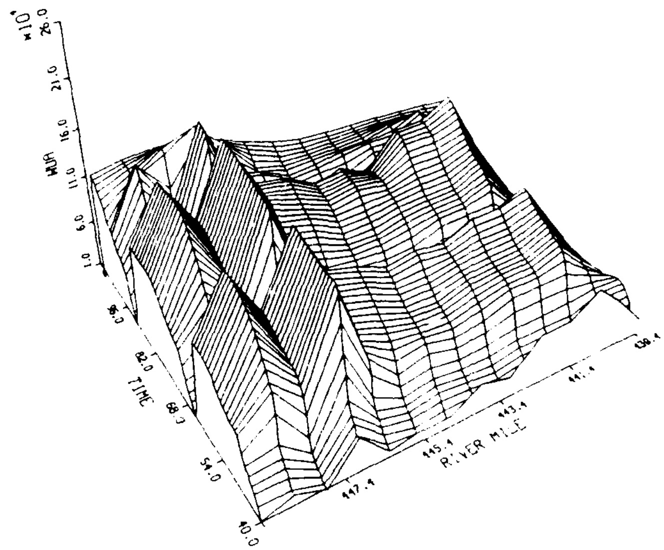
Species = Juvenile Brown Trout

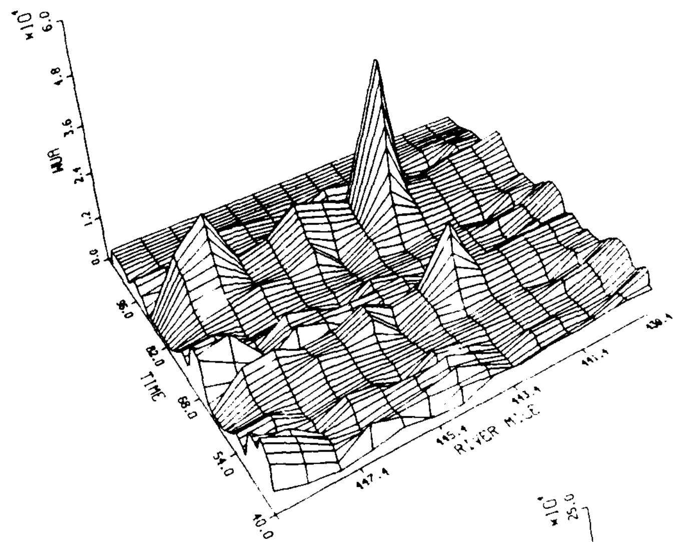


Species = Adult Rainbow Trout

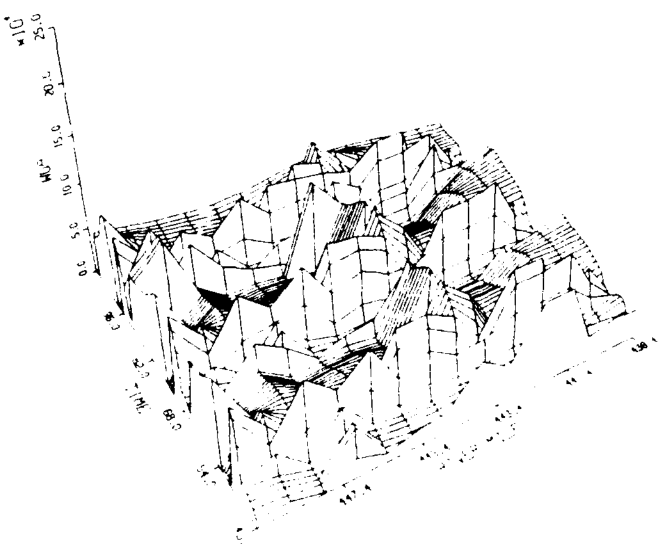
Cumberland River, September Uprate Conditions

Species = Adult Brown Trout



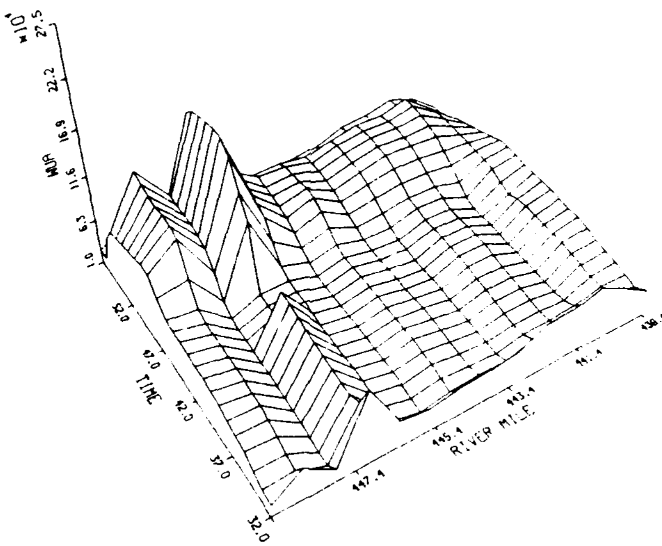


Species = Juvenile Brown Trout

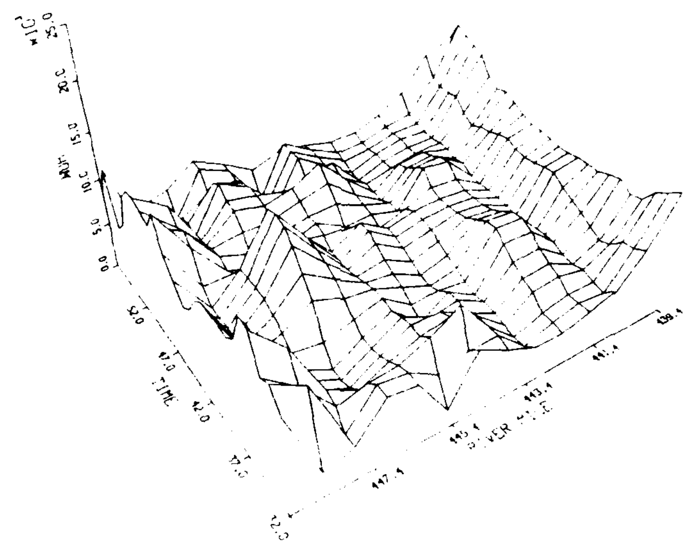


Species = Adult Rainbow Trout

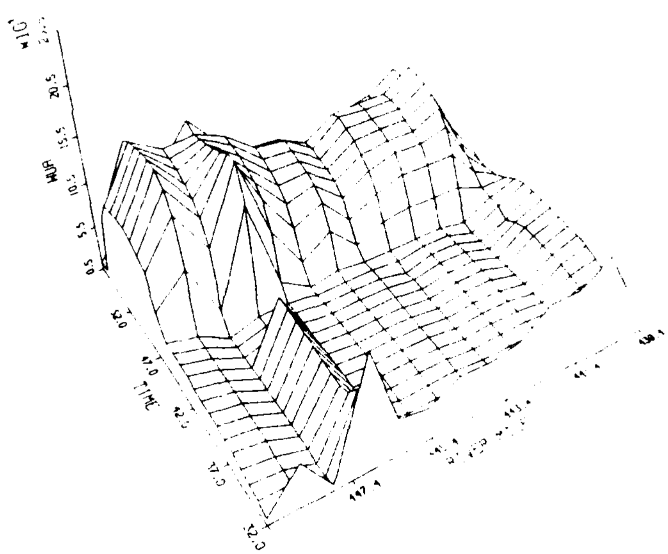
Cumberland River, 50-Percent Uprate Conditions



Species = Adult Brown Trout

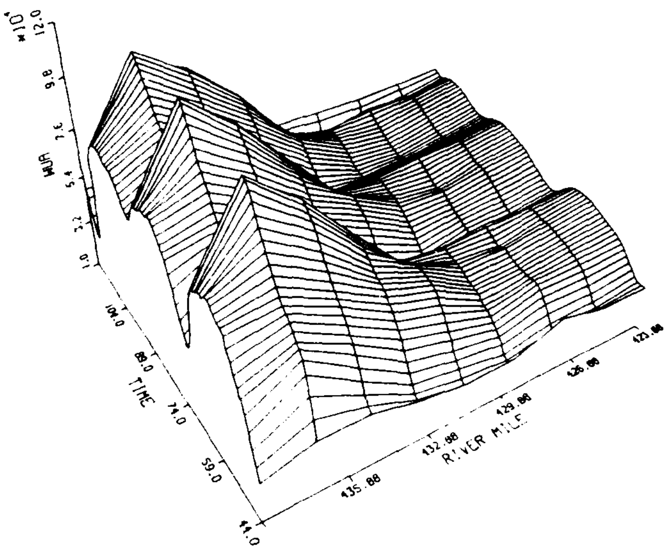


Species = Juvenile Brown Trout

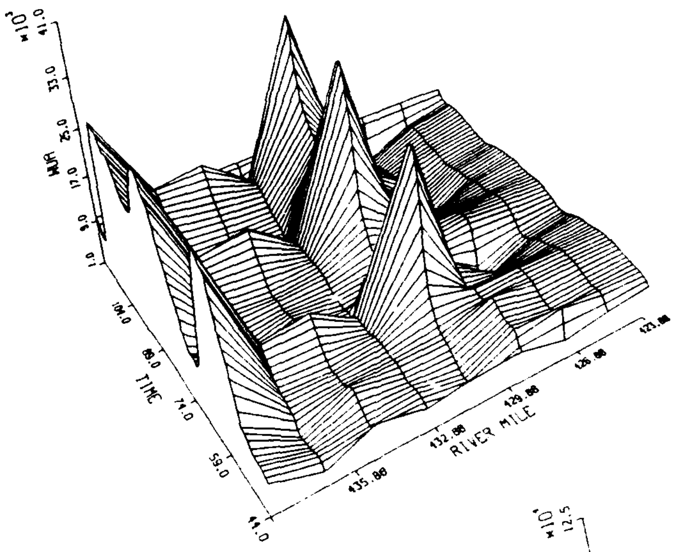


Species = Adult Rainbow Trout

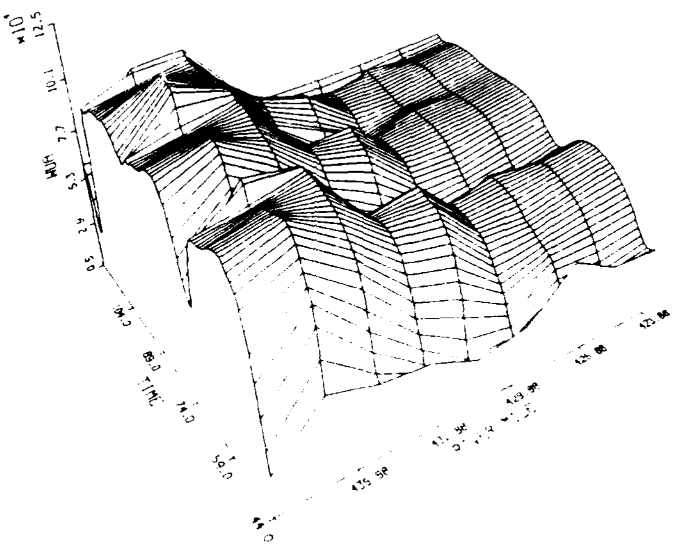
Cumberland River, 10-Percent Uprate Conditions



Species = Adult Brown Trout

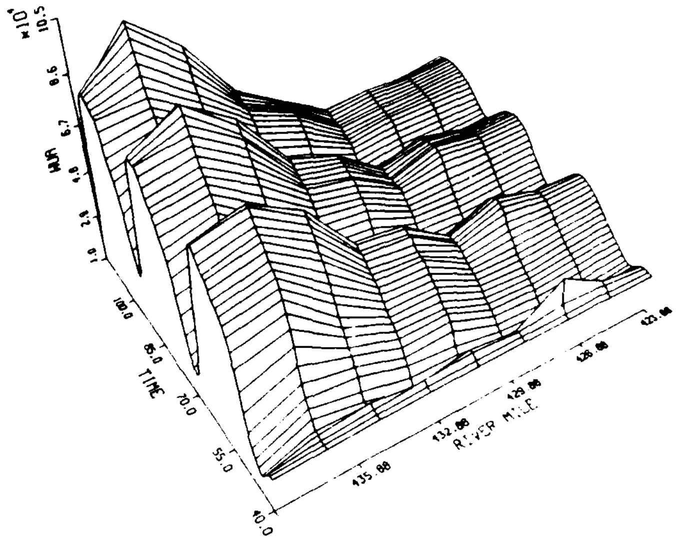


Species = Juvenile Brown Trout



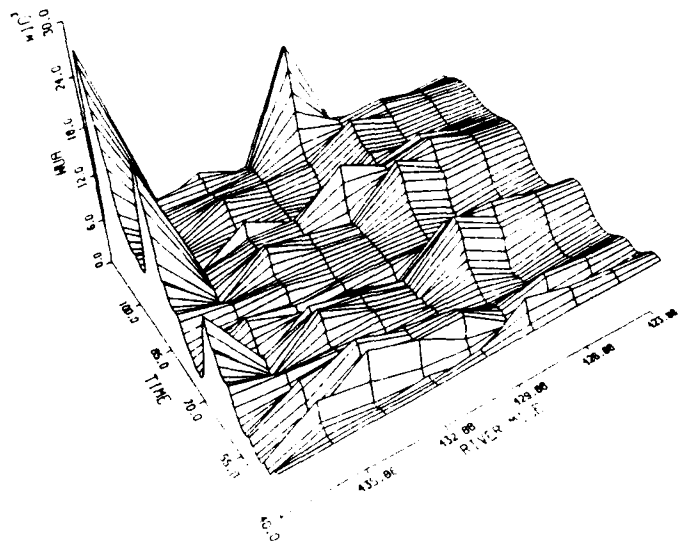
Species = Adult Rainbow Trout

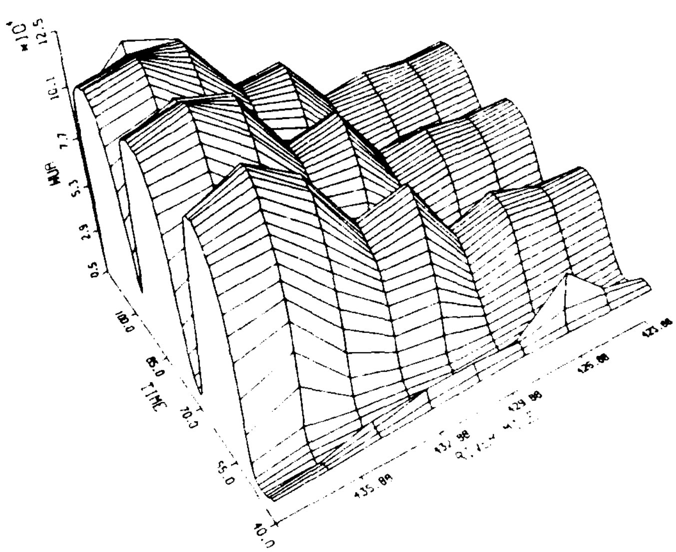
Cumberland River, September Existing Conditions



Species = Adult Brown Trout

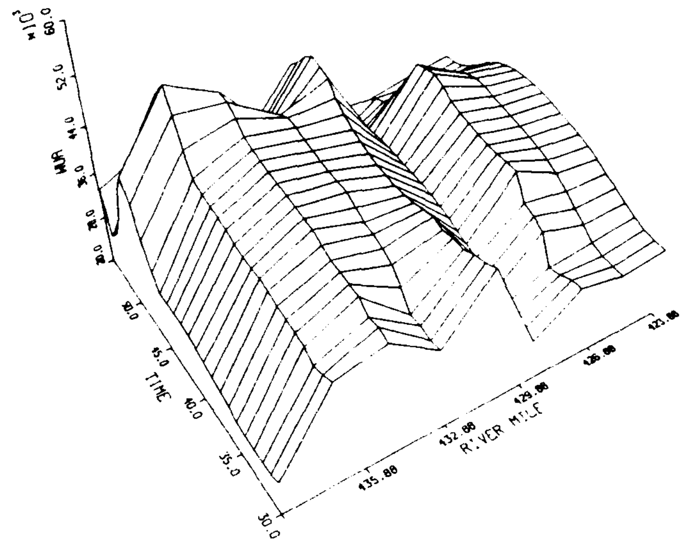
Species = Juvenile Brown Trout



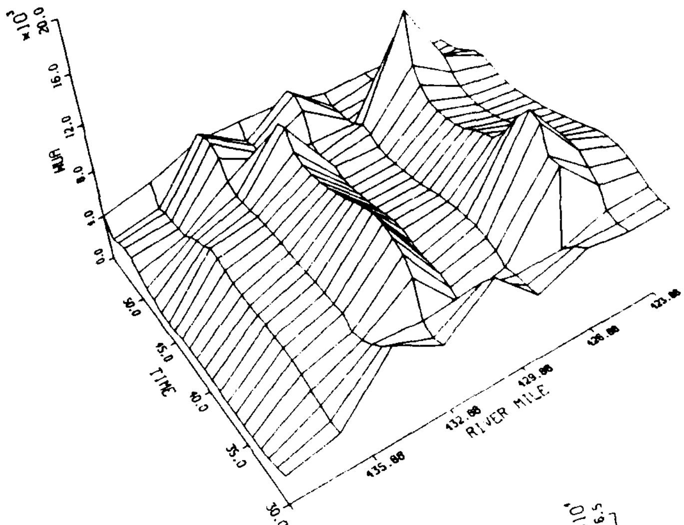


Species = Adult Rainbow Trout

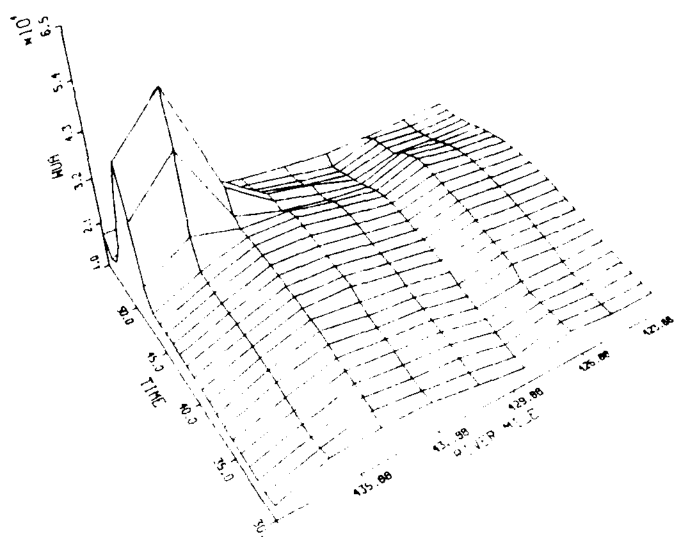
Cumberland River, 50-Percent Existing Conditions



Species = Adult Brown Trout

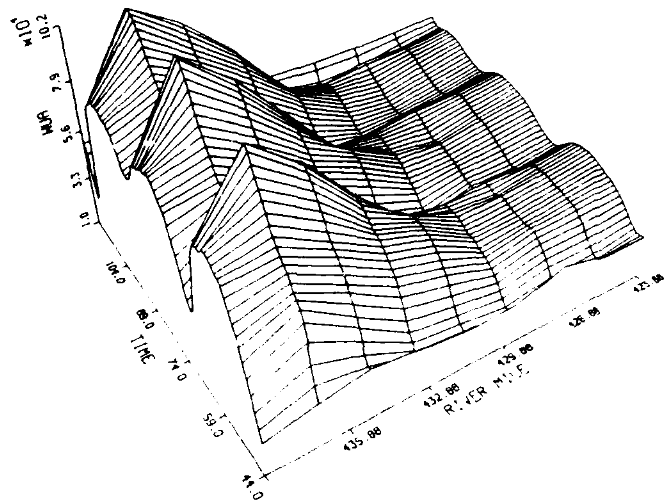


Species = Juvenile Brown Trout

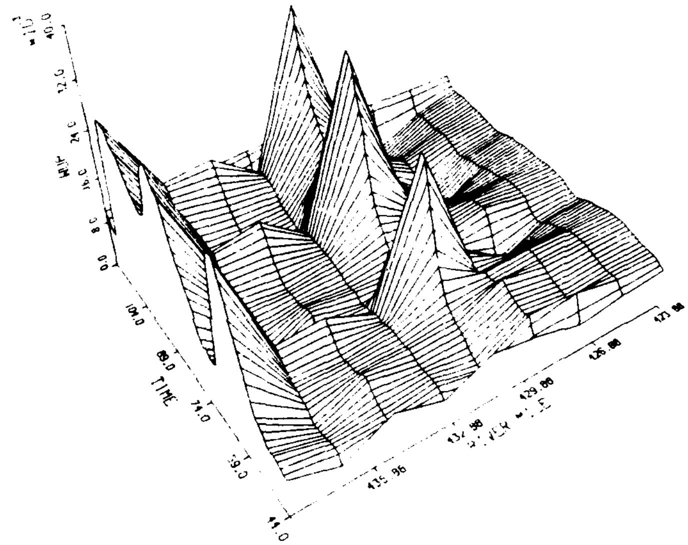


Species = Adult Rainbow Trout

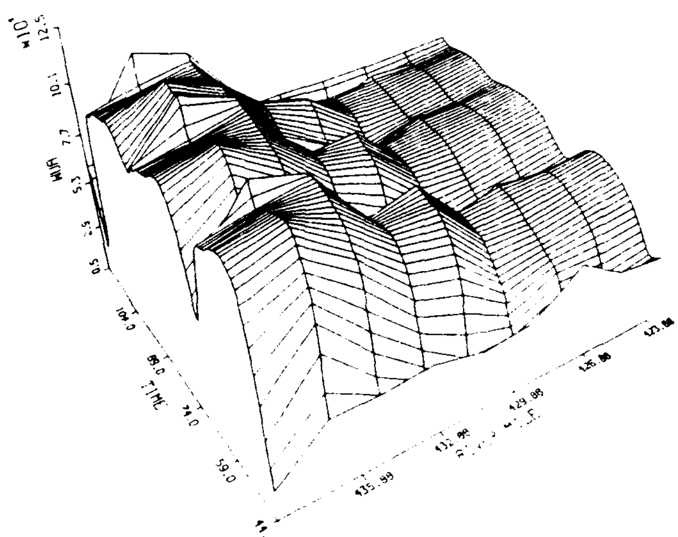
Cumberland River, 10-Percent Existing Conditions



Species = Adult Brown Trout



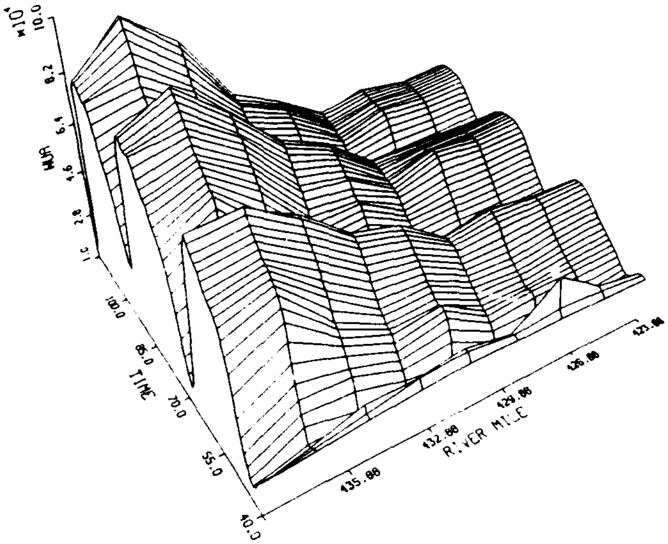
Species = Juvenile Brown Trout

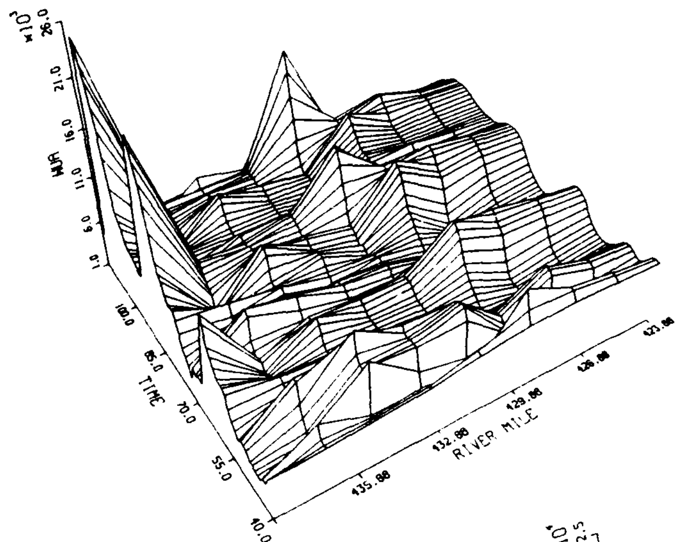


Species = Adult Rainbow Trout

Cumberland River, September Uprate Conditions

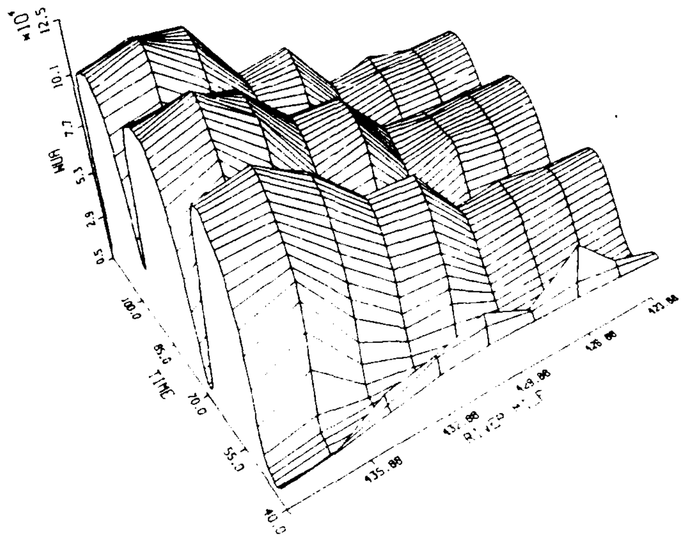
Species = Adult Brown Trout



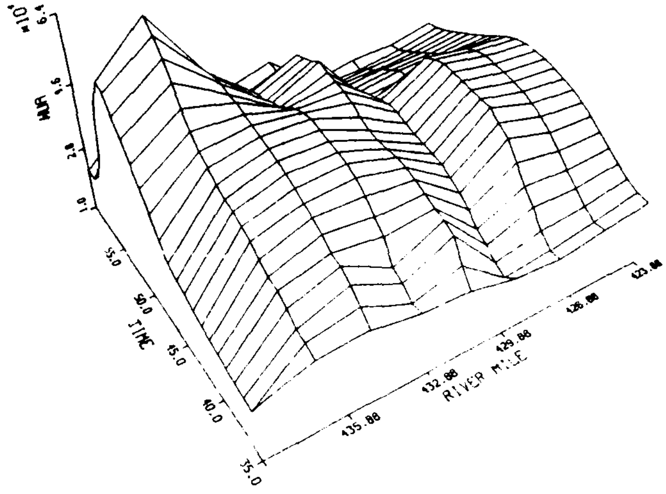


Species = Juvenile Brown Trout

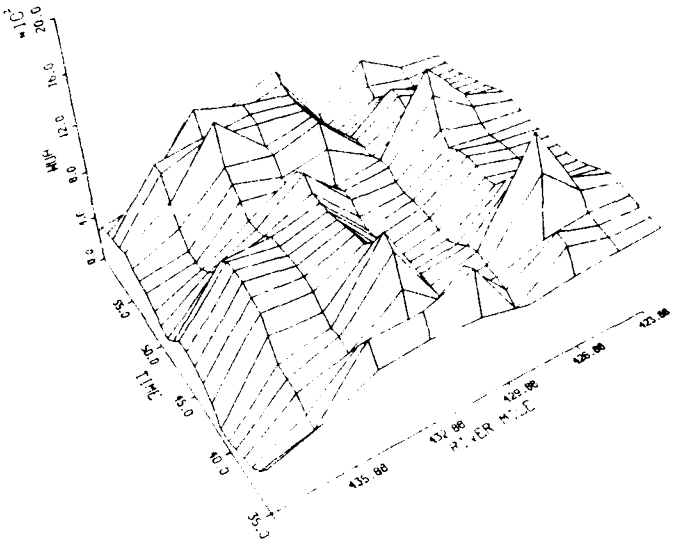
Species = Adult Rainbow Trout



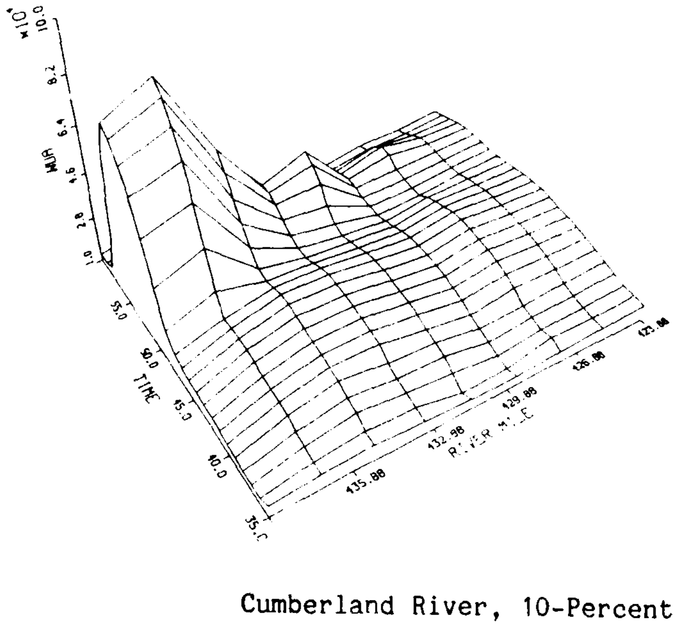
Cumberland River, 50-Percent Uprate Conditions



Species = Adult Brown Trout



Species = Juvenile Brown Trout



Species = Adult Rainbow Trout

Cumberland River, 10-Percent Uprate Conditions

APPENDIX E: MINIMUM AND AVERAGE WUA SUMMARY TABLES

TABLE E1

Minimum WUA per 1,000 Feet of Stream by Cross Section, Minimum WUA for the River Represented by Each Cross Section and Total Minimum WUA for Adult Rainbow Trout, Adult Brown Trout, and Juvenile Brown Trout

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
FLOW CONDITIONS: 10% EXISTING							
450.26	38867.10	51545.30	3024.00	4.092	159044.19	210923.38	12374.21
450.95	53190.60	59348.10	1944.70	2.482	132019.08	147302.00	4826.75
451.20	32181.40	33553.80	0.00	1.980	63719.17	66436.52	0.00
451.70	42428.70	48406.90	0.00	4.118	174721.39	199339.61	0.00
452.76	21907.80	36758.50	2105.40	3.907	85593.78	143615.47	8225.80
453.18	38888.70	57075.90	432.00	5.122	199187.92	292342.75	2212.70
454.70	25644.30	50673.50	3827.00	5.861	150301.25	296997.38	22430.05
455.10	49669.10	71812.20	0.00	3.168	157351.72	227501.06	0.00
455.90	23246.60	33492.60	3222.30	4.910	114140.80	164448.67	15821.49
457.16	65009.00	70659.20	2981.60	3.960	257435.64	279810.44	11807.14
457.40	19026.40	46332.70	30434.50	5.544	105482.37	256868.48	168728.88
459.26	24482.60	62703.10	2417.20	6.864	168048.56	430394.09	16591.66
460.00	29191.20	41344.70	2311.80	4.393	128236.95	181627.27	10155.74
TOTAL CROSS SECTION AVERAGES					1895283.00	2897607.00	273174.44
FLOW CONDITIONS: 10% UPGRADE							
450.26	32787.50	42057.30	1918.30	4.092	134166.45	172098.47	7849.68
450.95	44773.60	44183.50	638.60	2.482	111128.09	109663.45	1585.01
451.20	27346.90	25201.20	0.00	1.980	54146.86	49898.38	0.00
451.70	38467.20	39051.00	0.00	4.118	158407.92	160812.02	0.00
452.76	17620.20	26759.80	2113.40	3.907	68842.12	104550.55	8257.05
453.18	32206.00	45467.50	571.30	5.122	164959.14	232884.55	2926.20
454.70	18966.50	38281.60	355.00	5.861	111162.66	224368.47	2080.66
455.10	43822.80	60365.10	0.00	3.168	138830.63	191236.64	0.00
455.90	21160.60	29780.00	3222.30	4.910	103898.54	146219.80	15821.49
457.16	62210.10	56749.90	1821.40	3.960	246352.00	224729.59	7212.74
457.40	18484.30	37925.30	2791.30	5.544	102476.97	210257.88	15474.97
459.26	19730.70	49671.40	1566.80	6.864	135431.52	340944.47	10754.52
460.00	24456.20	28818.90	612.90	4.393	107436.09	126601.43	2692.47
TOTAL CROSS SECTION AVERAGES					1637239.13	2294265.75	74654.79

(CONTINUED)

NOTE: Reach multiplier is the length of river represented by each cross section. To obtain average WUA for the reach of river represented by each cross section, multiply the WUA per 1000 ft times the reach multiplier.

TABLE E1 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS: 10% EXISTING				
439.94	25945.80	48469.80	10223.90	3.617	93845.96	175315.28	36979.85
440.25	20386.10	45263.00	3844.30	2.851	58120.77	129044.81	10960.10
441.02	15763.30	30669.60	3134.00	5.042	79478.55	154636.11	15801.63
442.16	15274.10	35723.10	4049.00	5.333	81456.77	190511.31	21593.32
443.04	14143.30	26594.50	3075.30	2.693	38087.91	71618.99	8281.78
443.38	11359.80	32271.40	1434.90	1.954	22197.05	63058.32	2803.79
443.78	16331.60	31296.60	4107.10	3.722	60786.21	116485.94	15286.63
444.79	14242.10	35860.60	2355.40	4.224	60158.63	151475.19	9949.21
445.38	12896.50	28394.90	5937.10	5.808	74902.88	164917.58	34482.68
446.99	19383.40	37384.10	859.20	5.201	100813.07	194434.72	4468.70
447.35	167826.59	131458.30	6198.90	2.851	478473.63	374787.63	17673.06
448.07	8895.50	20565.50	3409.50	3.036	27006.74	62436.86	10351.24
448.50	22884.00	44643.90	6941.70	3.511	80345.72	156744.72	24372.31
449.40	21865.00	37128.60	11965.10	4.646	101584.79	172499.48	55589.85
TOTAL CROSS SECTION AVERAGES					1357258.75	2177967.00	268594.19
			FLOW CONDITIONS: 10% UPGRADE				
439.94	15931.80	33167.10	9554.00	3.617	57625.32	119965.41	34556.82
440.25	18110.30	39499.10	3800.00	2.851	51632.47	112611.94	10833.80
441.02	12405.20	25427.70	2892.50	5.042	62547.02	128206.45	14583.98
442.16	13293.50	29334.20	3225.30	5.333	70894.23	156439.30	17200.53
443.04	11201.70	20242.80	2053.20	2.693	30166.18	54513.86	5529.27
443.38	9916.20	25266.90	1669.70	1.954	19376.26	49371.52	3262.59
443.78	13553.80	24825.30	2716.30	3.722	50447.24	92399.77	10110.07
444.79	11076.90	25478.10	2820.00	4.224	46788.83	107619.49	11911.68
445.38	10115.60	18882.00	1905.10	5.808	58751.40	109666.66	11064.82
446.99	15827.10	27577.90	1036.30	5.201	82316.75	143432.67	5389.80
447.35	114786.00	99933.70	6234.70	2.851	327254.91	284911.00	17775.13
448.07	7026.70	13946.20	2762.90	3.036	21333.06	42340.66	8388.16
448.50	17089.90	29319.60	2522.90	3.511	60002.64	102941.11	8857.90
449.40	12973.80	24733.10	6358.10	4.646	60276.27	114909.98	29539.73
TOTAL CROSS SECTION AVERAGES					999412.63	1619329.88	189004.30

(CONTINUED)

TABLE E1 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juve-nile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juve-nile Brown Trout WUA C/S Total
			FLOW CONDITIONS: 10% EXISTING				
427.80	18101.70	31169.80	6494.90	4.514	81711.07	140700.48	29317.98
428.64	12862.00	23973.10	4457.90	6.890	88619.18	165174.66	30714.93
430.41	15199.20	26140.30	3871.60	7.339	111546.94	191843.67	28413.67
431.42	16608.80	42014.00	5134.30	5.518	91647.37	231833.25	28331.07
432.50	14613.00	30802.60	5544.10	5.861	85646.80	180534.03	32493.97
433.64	19254.70	34546.70	5383.70	7.735	148935.09	267218.72	41642.92
435.43	19098.90	40163.40	6039.80	9.768	186558.05	392316.06	58996.76
437.34	17541.20	37034.50	3456.70	9.108	159765.23	337310.22	31483.62
438.88	13700.60	24871.00	530.20	6.864	94040.91	170714.55	3639.29
TOTAL CROSS SECTION AVERAGES					1048470.75	2077645.75	285034.22
			FLOW CONDITIONS: 10% UPGRADE				
427.80	15415.40	23353.60	7128.30	4.514	69585.12	105418.15	32177.14
428.64	10669.10	17630.90	3705.70	6.890	73510.09	121476.90	25532.27
430.41	13152.00	24104.60	3789.50	7.339	96522.53	176903.66	27811.14
431.42	11748.50	32526.40	3972.40	5.518	64828.22	179480.69	21919.70
432.50	12930.20	23516.00	4231.70	5.861	75783.91	137827.28	24801.99
433.64	15862.10	28405.20	5463.50	7.735	122693.34	219714.22	42260.17
435.43	16972.70	33200.60	5991.70	9.768	165789.31	324303.47	58526.93
437.34	15681.20	32961.30	3760.90	9.108	142824.38	300211.53	34254.28
438.88	12458.40	21250.20	411.80	6.864	85514.46	145861.36	2826.59
TOTAL CROSS SECTION AVERAGES					897051.38	1711197.38	270110.22

(CONTINUED)

TABLE E1 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juve-nile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juve-nile Brown Trout WUA C/S Total
FLOW CONDITIONS: 50% EXISTING							
450.26	27138.60	35009.80	1495.70	4.092	111051.15	143260.11	6120.40
450.95	37254.30	35743.10	1600.90	2.482	92465.18	88714.38	3973.43
451.20	13422.00	16416.40	0.00	1.980	26575.56	32504.47	0.00
451.70	32935.40	37743.70	778.80	4.118	135627.97	155428.55	3207.10
452.76	12361.40	18856.90	2105.70	3.907	48295.99	73673.91	8226.97
453.18	24801.80	34459.10	3410.20	5.122	127034.83	176499.53	17467.04
454.70	18438.90	28439.30	2855.90	5.861	108070.40	166682.75	16738.43
455.10	41919.50	58192.00	1449.90	3.168	132800.97	184352.25	4593.28
455.90	21164.00	28585.60	2817.40	4.910	103915.23	140355.30	13833.43
457.16	47390.00	59812.40	1777.70	3.960	187664.41	236857.09	7039.69
457.40	17445.30	31363.90	4411.70	5.544	96716.75	173881.47	24458.47
459.26	18204.60	38026.60	2936.50	6.864	124956.37	261014.59	20156.13
460.00	21350.50	27649.50	3185.70	4.393	93792.75	121464.26	13994.78
TOTAL CROSS SECTION AVERAGES					1388967.63	1954688.75	139809.17
FLOW CONDITIONS: 50% UPGRADE							
450.26	28217.60	33098.90	1584.00	4.092	115466.41	135440.69	6481.73
450.95	34963.50	33068.60	1884.90	2.482	86779.41	82076.27	4678.32
451.20	15435.10	18436.60	0.00	1.980	30561.50	36504.47	0.00
451.70	31939.20	35341.20	397.70	4.118	131525.63	145535.06	1637.73
452.76	14865.00	17904.30	2105.60	3.907	58077.55	69952.10	8226.58
453.18	28126.40	31940.50	504.70	5.122	144063.42	163599.25	2585.07
454.70	14834.00	26337.10	3359.70	5.861	86942.08	154361.75	19691.20
455.10	46289.20	54501.80	0.00	3.168	146644.19	172661.70	0.00
455.90	20064.10	26922.30	2543.50	4.910	98514.73	132188.50	12488.58
457.16	47087.30	50219.20	1778.90	3.960	186465.72	198868.03	7044.44
457.40	15906.60	29524.10	3055.60	5.544	88186.19	163681.61	16940.25
459.26	15305.30	40822.70	2172.50	6.864	105055.58	280207.00	14912.04
460.00	20170.50	23730.30	1721.50	4.393	88609.01	104247.21	7562.55
TOTAL CROSS SECTION AVERAGES					1366891.50	1839323.75	102248.50

(CONTINUED)

TABLE E1 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS: 50% EXISTING				
439.94	7745.10	14483.00	6140.90	3.617	28014.03	52385.01	22211.63
440.25	16019.00	35255.50	4660.00	2.851	45670.17	100513.43	13285.66
441.02	16114.90	27114.00	2686.20	5.042	81251.33	136708.78	13543.82
442.16	11732.10	24543.00	3337.40	5.333	62567.29	130887.82	17798.35
443.04	9171.70	17475.20	1682.30	2.693	24699.39	47060.71	4530.43
443.38	6097.30	19644.60	1366.80	1.954	11914.12	38385.55	2670.73
443.78	13748.70	21031.40	3849.90	3.722	51172.66	78278.87	14329.33
444.79	7052.00	17538.20	2192.90	4.224	29787.65	74081.35	9262.81
445.38	8885.10	16050.40	1622.50	5.808	51604.66	93220.73	9423.48
446.99	13013.10	18430.40	3416.90	5.201	67681.13	95856.52	17771.30
447.35	3286.80	98300.90	1544.00	2.851	9370.67	280255.88	4401.94
448.07	3877.30	10601.20	1858.30	3.036	11771.48	32185.24	5641.80
448.50	14818.10	23198.70	2215.70	3.511	52026.35	81450.63	7779.32
449.40	6647.00	14109.10	1287.70	4.646	30881.96	65550.88	5982.65
TOTAL CROSS SECTION AVERAGES					558412.88	1306821.50	148633.28
			FLOW CONDITIONS: 50% UPGRADE				
439.94	7242.20	13425.20	5028.30	3.617	26195.04	48558.95	18187.36
440.25	13688.40	32166.60	4587.70	2.851	39025.63	91706.98	13079.53
441.02	12554.20	20963.10	2869.00	5.042	63298.27	105695.95	14465.50
442.16	10404.50	21967.00	3213.70	5.333	55487.20	117150.02	17138.66
443.04	8022.50	14929.60	2256.30	2.693	21604.59	40205.41	6076.22
443.38	3788.50	15958.70	1289.20	1.954	7402.73	31183.30	2519.10
443.78	10638.70	17950.50	3812.10	3.722	39597.24	66811.76	14188.64
444.79	5922.90	13777.40	2153.00	4.224	25018.33	58195.74	9094.27
445.38	7717.60	14423.10	1690.10	5.808	44823.82	83769.37	9816.10
446.99	10470.30	16625.70	3188.70	5.201	54456.03	86470.27	16584.43
447.35	94555.10	74739.20	1529.30	2.851	269576.59	213081.47	4360.03
448.07	1941.00	8355.70	1450.10	3.036	5892.88	25367.91	4402.50
448.50	11316.00	21929.40	3010.90	3.511	39730.48	76994.13	10571.27
449.40	9870.00	10574.20	1223.50	4.646	45856.02	49127.73	5684.38
TOTAL CROSS SECTION AVERAGES					737964.88	1094319.00	146167.98

(CONTINUED)

TABLE E1 (CONTINUED)

FLOW CONDITIONS: 50% EXISTING

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
427.80	15393.00	17990.00	3108.10	4.514	69484.00	81206.86	14029.96
428.64	10651.10	13834.20	2865.50	6.890	73386.08	95317.64	19743.29
430.41	12472.80	19696.40	4987.70	7.339	91537.88	144551.89	36604.73
431.42	7488.50	18960.80	3814.90	5.518	41321.54	104625.70	21050.62
432.50	12828.60	20895.20	3091.60	5.861	75188.42	122466.77	18119.87
433.64	13055.20	16142.90	4644.70	7.735	100981.98	124865.34	35926.76
435.43	12698.00	24103.70	4097.50	9.768	124034.06	235444.92	40024.38
437.34	12285.10	22503.60	2856.80	9.108	111892.69	204962.78	26019.73
438.88	11948.50	17816.00	2917.10	6.864	82014.50	122289.02	20022.97
TOTAL CROSS SECTION AVERAGES					769841.19	1235730.88	231542.31

FLOW CONDITIONS: 50% UPGRADE

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
427.80	13243.00	15570.20	3048.40	4.514	59778.90	70283.88	13760.48
428.64	9163.80	12486.50	2514.20	6.890	63138.58	86031.98	17322.84
430.41	10403.80	18413.10	5007.90	7.339	76353.49	135133.73	36752.98
431.42	6612.20	16949.60	3850.60	5.518	36486.12	93527.89	21247.61
432.50	10712.20	18150.70	2942.40	5.861	62784.21	106381.25	17245.41
433.64	9570.20	15460.60	5092.60	7.735	74025.50	119587.74	39391.26
435.43	10085.30	18998.60	4734.50	9.768	98513.20	185578.31	46246.59
437.34	9015.30	19792.90	2865.50	9.108	82111.35	180273.73	26098.97
438.88	10307.30	14571.80	3080.80	6.864	70749.30	100020.83	21146.61
TOTAL CROSS SECTION AVERAGES					623940.69	1076819.38	239212.73

TABLE E1 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
FLOW CONDITIONS: SEPTEMBER EXISTING							
450.26	26236.40	34446.20	4693.60	4.092	107359.35	140953.84	19206.21
450.95	37426.00	33826.00	3619.80	2.482	92891.34	83956.13	8984.34
451.20	15218.00	17911.70	3022.30	1.980	30131.64	35465.16	5984.15
451.70	34125.60	38611.10	3381.40	4.118	140529.23	159000.52	13924.60
452.76	14277.60	16915.20	3150.90	3.907	55782.58	66087.69	12310.57
453.18	28441.40	29758.60	3913.80	5.122	145676.86	152423.55	20046.48
454.70	19576.50	26798.60	2942.70	5.861	114737.87	157066.59	17247.16
455.10	41955.10	59783.70	2544.30	3.168	132913.77	189394.77	8060.34
455.90	21643.00	29493.30	3276.20	4.910	106267.13	144812.11	16086.14
457.16	46640.20	64188.90	2003.30	3.960	184695.19	254188.05	7933.07
457.40	16503.70	26794.50	4416.70	5.544	91496.51	148548.72	24486.19
459.26	17087.60	34671.40	2228.10	6.864	117289.28	237984.47	15293.68
460.00	21501.70	26568.80	3507.20	4.393	94456.97	116716.74	15407.13
TOTAL CROSS SECTION AVERAGES					1414227.75	1886598.38	184970.08
FLOW CONDITIONS: SEPTEMBER UPGRADE							
450.26	27865.70	35782.80	4704.90	4.092	114026.45	146423.22	19252.45
450.95	36432.90	34395.10	3445.40	2.482	90426.46	85368.65	8551.48
451.20	16337.40	20202.00	2910.50	1.980	32348.05	39999.96	5762.79
451.70	33452.50	39928.90	3255.60	4.118	137757.39	164427.20	13406.56
452.76	15373.80	18159.30	3819.70	3.907	60065.44	70948.39	14923.57
453.18	22691.70	28362.40	3403.30	5.122	116226.89	145272.22	17431.70
454.70	20034.60	26272.50	2488.00	5.861	117422.79	153983.13	14582.17
455.10	41875.80	59170.20	2049.50	3.168	132662.53	187451.19	6492.82
455.90	22698.40	26466.70	3230.30	4.910	111449.14	129951.49	15860.77
457.16	46627.40	66371.70	1861.70	3.960	184644.50	262831.94	7372.33
457.40	16171.80	26290.70	5005.70	5.544	89656.46	145755.64	27751.60
459.26	15841.70	36295.40	2346.60	6.864	108737.43	249131.61	16107.06
460.00	20643.20	23633.10	3516.60	4.393	90685.58	103820.21	15448.42
TOTAL CROSS SECTION AVERAGES					1386109.25	1885365.00	182943.75

(CONTINUED)

TABLE E1 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS: SEPTEMBER EXISTING				
439.94	7932.70	13155.40	4887.10	3.617	28692.58	47583.09	17676.64
440.25	76393.50	52887.00	6114.70	2.851	217797.88	150780.84	17433.01
441.02	73473.60	50256.30	2820.20	5.042	370453.88	253392.27	14219.45
442.16	38234.70	31608.30	4236.50	5.333	203905.66	168567.08	22593.26
443.04	11959.50	17685.50	5092.90	2.693	32206.93	47627.05	13715.18
443.38	14511.60	21319.70	2233.30	1.954	28355.67	41658.69	4363.87
443.78	27137.40	28377.50	3881.80	3.722	101005.40	105621.05	14448.06
444.79	17720.10	21031.60	2217.40	4.224	74849.70	88837.48	9366.30
445.38	19134.60	22864.90	3430.70	5.808	111133.76	132799.34	19925.51
446.99	11764.40	19785.90	3203.70	5.201	61186.65	102906.47	16662.44
447.35	101184.20	108338.10	1536.80	2.851	288476.16	308871.94	4381.42
448.07	5340.10	10855.60	1864.70	3.036	16212.54	32957.60	5661.23
448.50	16380.40	28200.10	3970.10	3.511	57511.59	99010.55	13939.02
449.40	3239.00	13509.40	1426.20	4.646	15048.39	62764.67	6626.13
TOTAL CROSS SECTION AVERAGES					1606836.75	1643378.25	181011.50
			FLOW CONDITIONS: SEPTEMBER UPGRADE				
439.94	7300.60	13873.30	5129.00	3.617	26406.27	50179.73	18551.59
440.25	70325.20	50090.20	6304.20	2.851	200497.16	142807.16	17973.28
441.02	61313.50	46845.60	3005.10	5.042	309142.66	236195.52	15151.71
442.16	38492.00	31661.50	4191.90	5.333	205277.84	168850.78	22355.40
443.04	12713.80	17348.90	4585.40	2.693	34238.27	46720.59	12348.48
443.38	12924.20	20058.60	1889.10	1.954	25253.89	39194.50	3691.30
443.78	25012.60	27899.90	4030.70	3.722	93096.89	103843.43	15002.26
444.79	12528.10	18483.10	2063.00	4.224	52918.69	78072.61	8714.11
445.38	14920.20	19701.80	3550.90	5.808	86656.52	114428.06	20623.63
446.99	12971.00	19939.80	2942.10	5.201	67462.17	103706.91	15301.86
447.35	101112.20	107920.70	1529.30	2.851	288270.91	307681.94	4360.03
448.07	5077.50	11329.60	1543.00	3.036	15415.29	34396.66	4684.55
448.50	14220.90	24568.60	3762.60	3.511	49929.58	86260.35	13210.49
449.40	7740.90	15935.80	1344.70	4.646	35964.22	74037.73	6247.48
TOTAL CROSS SECTION AVERAGES					1490530.25	1586376.00	178216.17

(CONTINUED)

TABLE E1 (CONCLUDED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
FLOW CONDITIONS: SEPTEMBER EXISTING							
427.80	36054.10	26589.90	1596.40	4.514	162748.22	120026.81	7206.15
428.64	9958.20	13089.50	2748.30	6.890	68612.00	90186.66	18935.79
430.41	21851.50	26921.20	10323.30	7.339	160368.16	197574.69	75762.70
431.42	18174.20	23517.00	3754.70	5.518	100285.23	129766.81	20718.44
432.50	66656.70	44026.70	4352.60	5.861	390674.94	258040.48	25510.59
433.64	30185.90	26178.80	4474.50	7.735	233487.94	202493.03	34610.26
435.43	45857.80	36497.40	5746.50	9.768	447938.97	356506.56	56131.81
437.34	52925.80	35131.60	2855.40	9.108	482048.19	319978.63	26006.98
438.88	27819.80	28573.30	7121.10	6.864	190955.11	196127.13	48879.23
TOTAL CROSS SECTION AVERAGES					2237118.75	1870700.88	313761.94
FLOW CONDITIONS: SEPTEMBER UPGRADE							
427.80	35397.90	26318.80	1591.90	4.514	159786.11	118803.06	7185.84
428.64	9682.30	12572.90	2678.10	6.890	66711.05	86627.28	18452.11
430.41	20835.80	25739.30	10467.70	7.339	152913.95	188900.73	76822.45
431.42	16186.10	23023.80	3487.30	5.518	89314.90	127045.34	19242.92
432.50	59880.90	40588.50	4038.50	5.861	350961.94	237889.20	23669.65
433.64	26246.70	24635.80	4648.80	7.735	203018.22	190557.92	35958.47
435.43	40948.90	34762.30	5444.00	9.768	399988.81	339558.16	53176.99
437.34	43750.20	31333.30	3057.70	9.108	398476.81	285383.69	27849.53
438.88	21581.80	26334.80	6867.80	6.864	148137.48	180762.06	47140.58
TOTAL CROSS SECTION AVERAGES					1969309.50	1755527.63	309498.56

TABLE E2

Average WUA per 1,000 Feet of Stream by Cross Section, Average WUA for the River Represented by Each Cross Section and Total Average WUA for Adult Rainbow Trout, Adult Brown Trout, and Juvenile Brown Trout

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS:	10% EXISTING			
450.26	53485.61	66993.38	9719.09	4.092	218863.11	274136.94	39770.52
450.95	64668.75	72070.46	4197.18	2.482	160507.84	178878.89	10417.40
451.20	48725.56	46033.38	13354.53	1.980	96476.61	91146.09	26441.97
451.70	59017.45	61076.57	957.61	4.118	243033.86	251513.31	3943.44
452.76	41701.45	56592.66	6736.27	3.907	162927.56	221107.53	26318.61
453.18	53564.55	74814.42	4143.73	5.122	274357.66	383199.50	21224.19
454.70	59286.14	80948.71	6045.04	5.861	347476.06	474440.41	35429.98
455.10	66462.44	85727.01	1828.01	3.168	210553.00	271583.16	5791.14
455.90	52984.95	88651.07	28269.07	4.910	260156.09	435276.75	138801.13
457.16	104939.56	99541.52	11862.08	3.960	415560.66	394184.44	46973.84
457 40	41310.50	73742.87	4017.31	5.544	229025.42	408830.47	22271.97
459.26	37767.37	85598.74	5394.36	6.864	259235.23	587549.75	37026.89
460.00	39426.13	66621.79	3839.09	4.393	173198.98	292669.53	16865.12
TOTAL CROSS SECTION AVERAGES					3051372.25	4264517.00	431276.19
			FLOW CONDITIONS:	10% UPGRADE			
450.26	67708.83	74580.99	6718.94	4.092	277064.53	305185.41	27493.90
450.95	72771.59	78645.85	3481.25	2.482	180619.11	195199.02	8640.46
451.20	56721.84	57229.89	10853.35	1.980	112309.24	113315.19	21489.63
451.70	74528.28	71687.50	3303.38	4.118	306907.47	295209.13	13603.32
452.76	62656.81	71519.22	6197.81	3.907	244800.16	279425.59	24214.84
453.18	65868.70	82741.98	5078.39	5.122	337379.50	423804.44	26011.52
454.70	82713.20	101228.23	4783.23	5.861	484782.09	593298.63	28034.51
455.10	81593.30	98883.83	2289.06	3.168	258487.56	313263.97	7251.74
455.90	72351.73	98087.94	13706.16	4.910	355246.97	481611.75	67297.24
457.16	91495.75	106707.75	9118.07	3.960	362323.19	422562.69	36107.56
457.40	61352.34	94057.20	5348.92	5.544	340137.38	521453.16	29654.41
459.26	43483.64	93207.16	5432.85	6.864	298471.69	639773.88	37291.08
460.00	45408.27	81425.26	3442.23	4.393	199478.53	357701.16	15121.72
TOTAL CROSS SECTION AVERAGES					3758007.75	4941804.00	342211.97

(CONTINUED)

NOTE: Reach multiplier is the length of river represented by each cross section. To obtain average WUA for the reach of river represented by each cross section, multiply the WUA per 1000 ft times the reach multiplier.

TABLE E2 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS: 10% EXISTING				
439.94	36780.11	57732.09	11845.02	3.617	133033.66	208816.97	42843.44
440.25	34351.06	51886.63	5072.60	2.851	97934.87	147928.78	14461.98
441.02	32507.71	39891.13	4167.28	5.042	163903.88	201131.06	21011.42
442.16	31747.85	45248.54	8386.21	5.333	169311.28	241310.47	44723.66
443.04	19613.11	31550.00	4528.29	2.693	52818.11	84964.16	12194.69
443.38	31531.24	42774.61	2372.46	1.954	61612.04	83581.59	4635.79
443.78	25098.85	38332.38	5508.79	3.722	93417.91	142673.11	20503.72
444.79	29017.05	44820.82	5565.00	4.224	122568.02	189323.14	23506.56
445.38	23500.61	36334.78	6950.94	5.808	136491.55	211032.41	40371.06
446.99	35667.52	48143.95	3072.71	5.201	185506.78	250396.69	15981.17
447.35	190081.72	156434.59	7589.75	2.851	541923.00	445995.03	21638.38
448.07	24621.33	32501.89	4206.80	3.036	74750.36	98675.74	12771.84
448.50	49041.95	63056.04	9911.98	3.511	172186.28	221389.75	34800.96
449.40	39367.73	56076.64	13844.29	4.646	182902.47	260532.06	64320.57
TOTAL CROSS SECTION AVERAGES					2188360.25	2787751.00	373765.25
			FLOW CONDITIONS: 10% UPGRADE				
439.94	38750.25	54855.14	12496.82	3.617	140159.66	198411.05	45201.00
440.25	55578.07	59789.00	6194.07	2.851	158453.08	170458.44	17659.29
441.02	54609.80	50048.84	3964.47	5.042	275342.59	252346.23	19988.86
442.16	51548.40	54514.48	6436.56	5.333	274907.63	290725.72	34326.18
443.04	33445.51	36615.82	4498.09	2.693	90068.77	98606.41	12113.36
443.38	56635.80	53251.98	3391.46	1.954	110666.35	104054.37	6626.91
443.78	40100.46	44177.54	4995.06	3.722	149253.91	164428.80	18591.61
444.79	47453.14	51001.23	6541.76	4.224	200442.06	215429.20	27632.39
445.38	43084.57	44191.95	5481.51	5.808	250235.19	256666.84	31836.61
446.99	57055.25	57517.39	5652.98	5.201	296744.38	299147.97	29401.15
447.35	166832.59	169753.19	12885.79	2.851	475639.75	483966.34	36737.39
448.07	49592.16	45306.21	3992.29	3.036	150561.80	137549.66	12120.59
448.50	74769.14	75345.85	6755.20	3.511	262514.44	264539.28	23717.51
449.40	55118.23	62954.88	11989.78	4.646	256079.30	292488.38	55704.52
TOTAL CROSS SECTION AVERAGES					3091069.00	3228819.00	371657.38

(CONTINUED)

TABLE E2 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS: 10% EXISTING				
427.80	22018.92	40813.18	11428.32	4.514	99393.41	184230.69	51587.44
428.64	16782.72	29602.09	6412.18	6.890	115632.95	203958.39	44179.92
430.41	18038.46	28468.64	5286.48	7.339	132384.27	208931.36	38797.48
431.42	20962.92	46033.27	6548.56	5.518	115673.40	254011.59	36134.96
432.50	18366.57	36433.62	7660.60	5.861	107646.47	213537.45	44898.78
433.64	23960.71	42542.48	11148.10	7.735	185336.11	329066.09	86230.55
435.43	23960.24	45010.64	6920.04	9.768	234043.63	439663.91	67594.95
437.34	25154.44	42415.64	4888.31	9.108	229106.63	386321.66	44522.73
438.88	17915.88	28298.54	1620.85	6.864	122974.60	194241.17	11125.51
TOTAL CROSS SECTION AVERAGES					1342191.50	2413962.50	425072.28
			FLOW CONDITIONS: 10% UPGRADE				
427.80	22792.08	38439.57	10265.19	4.514	102883.45	173516.22	46337.07
428.64	16864.18	27269.85	5734.92	6.890	116194.20	187889.27	39513.60
430.41	19105.99	28719.51	5000.80	7.339	140218.86	210772.48	36700.87
431.42	24137.06	43872.09	7347.30	5.518	133188.30	242086.20	40542.40
432.50	23900.20	35872.43	6533.95	5.861	140079.06	210248.31	38295.48
433.64	25807.64	42332.71	11318.82	7.735	199622.11	327443.53	87551.08
435.43	30516.89	45329.80	8329.10	9.768	298088.97	442781.47	81358.64
437.34	39318.84	47354.41	6544.82	9.108	358116.00	431303.97	59610.22
438.88	29331.55	32159.54	2522.86	6.864	201331.77	220743.08	17316.91
TOTAL CROSS SECTION AVERAGES					1689722.75	2446784.50	447226.31

(CONTINUED)

TABLE E2 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS: 50% EXISTING				
450.26	82052.88	81542.23	12672.93	4.092	335760.41	333670.78	51857.63
450.95	78394.98	78492.06	9054.84	2.482	194576.34	194817.31	22474.11
451.20	56420.93	49955.69	7295.12	1.980	111713.45	98912.27	14444.34
451.70	95125.51	96240.61	7456.05	4.118	391726.84	396318.84	30704.01
452.76	81094.09	67291.74	15114.08	3.907	316834.63	262908.84	59050.71
453.18	68801.73	67539.75	20553.06	5.122	352402.47	345938.63	105272.78
454.70	80274.98	71525.30	37076.57	5.861	470491.66	419209.78	217305.78
455.10	92581.06	126019.09	13524.69	3.168	293296.81	399228.50	42846.22
455.90	78585.66	81423.33	12556.41	4.910	385855.56	399788.53	61651.97
457.16	70255.57	101552.09	16586.63	3.960	278212.06	402146.28	65683.06
457.40	72992.68	76397.20	38732.09	5.544	404671.44	423546.09	214730.72
459.26	41254.38	94204.18	7494.53	6.864	283170.06	646617.50	51442.45
460.00	53758.79	97968.01	9910.70	4.393	236162.36	430373.47	43537.71
TOTAL CROSS SECTION AVERAGES					4054874.00	4753477.00	981001.56
			FLOW CONDITIONS: 50% UPGRADE				
450.26	83718.65	82974.35	12534.14	4.092	342576.72	339531.06	51289.70
450.95	79824.16	80560.83	8835.26	2.482	198123.56	199951.98	21929.12
451.20	58355.62	51061.09	7168.97	1.980	115544.13	101100.96	14194.56
451.70	97526.90	97385.61	7124.19	4.118	401615.78	401033.94	29337.41
452.76	84931.63	70900.80	14091.38	3.907	331827.91	277009.41	55055.02
453.18	71637.19	71471.02	19122.56	5.122	366925.69	366074.59	97945.76
454.70	88989.17	79796.94	36934.58	5.861	521565.53	467689.84	216473.56
455.10	95074.87	127180.13	12692.34	3.168	301197.19	402906.66	40209.33
455.90	81735.94	86671.74	13969.73	4.910	401323.44	425558.25	68591.38
457.16	66476.93	103103.17	16597.58	3.960	263248.66	408288.56	65726.41
457.40	80352.20	82630.26	36903.90	5.544	445472.63	458102.16	204595.22
459.26	43449.58	98827.02	6802.00	6.864	298237.91	678348.69	46688.93
460.00	56248.11	103704.28	9219.30	4.393	247097.95	455572.91	40500.39
TOTAL CROSS SECTION AVERAGES					4234757.50	4981169.00	952536.81

(CONTINUED)

TABLE E2 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
FLOW CONDITIONS: 50% EXISTING							
439.94	36838.02	31703.26	10456.08	3.617	133243.13	114670.70	37819.64
440.25	113985.81	88897.99	7666.97	2.851	324973.56	253448.19	21858.53
441.02	115937.60	88585.91	6624.64	5.042	584557.38	446650.13	33401.43
442.16	97423.55	78826.37	5729.13	5.333	519559.78	420381.03	30553.45
443.04	77440.84	58476.66	7411.43	2.693	208548.20	157477.66	19958.98
443.38	107937.96	77361.11	12262.22	1.954	210910.78	151163.61	23960.38
443.78	71456.02	69947.43	5868.06	3.722	265959.31	260344.33	21840.92
444.79	83958.39	67394.08	5553.16	4.224	354640.25	284672.59	23456.55
445.38	87608.04	75507.23	6986.98	5.808	508827.50	438545.97	40580.38
446.99	96134.74	84042.02	6510.17	5.201	499996.81	437102.59	33859.39
447.35	151740.34	210769.64	6729.33	2.851	432611.72	600904.25	19185.32
448.07	99627.04	73522.82	6919.52	3.036	302467.69	223215.28	21007.66
448.50	106808.34	117046.91	7353.95	3.511	375004.09	410951.69	25819.72
449.40	70126.52	72077.91	5099.19	4.646	325807.81	334873.94	23690.84
TOTAL CROSS SECTION AVERAGES					5047108.00	4534402.00	376993.19

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
FLOW CONDITIONS: 50% UPGRADE							
439.94	38780.02	33127.69	10505.34	3.617	140267.33	119822.86	37997.82
440.25	114169.15	90187.05	7675.93	2.851	325496.25	257123.28	21884.08
441.02	115971.75	89718.43	6602.38	5.042	584729.56	452360.31	33289.20
442.16	97866.71	80636.25	5775.76	5.333	521923.19	430033.13	30802.13
443.04	79572.87	59772.23	7618.02	2.693	214289.73	160966.63	20515.33
443.38	110660.62	79562.49	12963.57	1.954	216230.84	155465.11	25330.82
443.78	71563.38	71438.82	5971.49	3.722	266358.91	265895.28	22225.89
444.79	85592.66	69518.25	5817.31	4.224	361543.38	293645.09	24572.32
445.38	89379.05	77904.68	7279.69	5.808	519113.50	452470.38	42280.44
446.99	99533.75	87613.86	6471.58	5.201	517675.06	455679.69	33658.69
447.35	142889.19	212671.69	6535.36	2.851	407377.09	606327.00	18632.31
448.07	105024.19	77292.98	7428.75	3.036	318853.44	234661.48	22553.69
448.50	109497.90	122153.73	7822.20	3.511	384447.13	428881.72	27463.74
449.40	72884.58	75821.16	5175.63	4.646	338621.75	352265.09	24045.98
TOTAL CROSS SECTION AVERAGES					5116927.50	4665597.00	385252.41

(CONTINUED)

TABLE E2 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
			FLOW CONDITIONS: 50% EXISTING				
427.80	45764.60	36138.38	6885.93	4.514	206581.41	163128.64	31083.09
428.64	24555.64	22263.85	6636.92	6.890	169188.36	153397.92	45728.38
430.41	42287.97	36136.79	10223.63	7.339	310351.41	265207.91	75031.22
431.42	53906.05	39250.54	6804.59	5.518	297453.59	216584.48	37547.73
432.50	73320.68	54347.64	5877.78	5.861	429732.50	318531.53	34449.67
433.64	49522.95	38618.73	6641.82	7.735	383060.03	298715.88	51374.48
435.43	76789.27	56714.26	7178.96	9.768	750077.63	553984.88	70124.08
437.34	91098.66	67414.70	5383.06	9.108	829726.56	614013.13	49028.91
438.88	77021.38	56816.79	9967.23	6.864	528674.75	389990.44	68415.07
TOTAL CROSS SECTION AVERAGES					3904846.25	2973555.00	462782.63
			FLOW CONDITIONS: 50% UPGRADE				
427.80	45298.35	36140.73	6989.22	4.514	204476.75	163139.25	31549.34
428.64	24416.91	22254.84	6490.14	6.890	168232.50	153335.84	44717.07
430.41	41900.24	35929.87	10049.98	7.339	307505.84	263689.34	73756.81
431.42	54078.46	39576.61	6864.80	5.518	298404.97	218383.73	37879.96
432.50	72349.88	53795.49	5877.21	5.861	424042.66	315295.38	34446.33
433.64	49077.52	38554.21	6720.95	7.735	379614.63	298216.81	51986.55
435.43	75984.83	56590.15	7191.17	9.768	742219.75	552772.56	70243.34
437.34	89915.08	67344.70	5411.46	9.108	818946.50	613375.56	49287.58
438.88	77221.32	57053.01	9953.05	6.864	530047.13	391611.88	68317.73
TOTAL CROSS SECTION AVERAGES					3873491.00	2969820.75	462184.75

(CONTINUED)

TABLE E2 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juvenile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juvenile Brown Trout WUA C/S Total
FLOW CONDITIONS: SEPTEMBER EXISTING							
450.26	85838.81	82082.95	26472.47	4.092	351252.41	335883.44	108325.35
450.95	79512.60	74841.45	17733.16	2.482	197350.28	185756.50	44013.71
451.20	57904.17	48748.85	11351.35	1.980	114650.26	96522.73	22475.67
451.70	103632.07	104189.78	11965.69	4.118	426756.88	429053.53	49274.71
452.76	72472.88	55708.36	22774.40	3.907	283151.56	217652.56	88979.59
453.18	55928.55	50372.93	29012.77	5.122	286466.06	258010.16	148603.41
454.70	63363.68	52602.33	39267.63	5.861	371374.53	308302.25	230147.58
455.10	96829.25	137265.59	18601.18	3.168	306755.06	434857.41	58928.54
455.90	85947.34	91708.66	14237.21	4.910	422001.44	450289.50	69904.70
457.16	59548.27	101803.51	23465.70	3.960	235811.16	403141.91	92924.17
457.40	60332.82	60232.89	53024.91	5.544	334485.16	333931.16	293970.13
459.26	43725.29	96767.92	6900.53	6.864	300130.38	664215.00	47365.23
460.00	59278.35	105759.58	13252.34	4.393	260409.81	464601.84	58217.53
TOTAL CROSS SECTION AVERAGES					3890595.50	4582218.50	1313130.38
FLOW CONDITIONS: SEPTEMBER UPGRADE							
450.26	85974.15	82240.27	25592.38	4.092	351806.22	336527.19	104724.02
450.95	79476.37	75145.40	17158.86	2.482	197260.36	186510.89	42588.29
451.20	57817.31	48893.11	11171.07	1.980	114478.27	96808.36	22118.72
451.70	103033.83	103868.31	11686.16	4.118	424293.31	427729.72	48123.61
452.76	73534.96	56583.39	22441.08	3.907	287301.09	221071.31	87677.30
453.18	56897.62	51255.61	28676.85	5.122	291429.63	262531.25	146882.83
454.70	64300.21	52784.59	38785.89	5.861	376863.53	309370.47	227324.11
455.10	96880.20	136378.67	18377.53	3.168	306916.47	432047.63	58220.01
455.90	85720.52	91152.85	14039.71	4.910	420887.75	447560.50	68934.98
457.16	59691.27	101920.53	23223.90	3.960	236377.42	403605.31	91966.65
457.40	61962.50	61222.41	52315.26	5.544	343520.09	339417.06	290035.81
459.26	43791.44	97066.30	6908.06	6.864	300584.44	666263.06	47416.92
460.00	59467.89	106028.23	13164.87	4.393	261242.45	465782.00	57833.28
TOTAL CROSS SECTION AVERAGES					3912961.00	4595225.00	1293846.50

(CONTINUED)

TABLE E2 (CONTINUED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juve-nile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juve-nile Brown Trout WUA C/S Total
			FLOW CONDITIONS: SEPTEMBER EXISTING				
439.94	46200.04	31529.12	14233.02	3.617	167105.55	114040.83	51480.83
440.25	129193.17	118898.79	11270.80	2.851	368329.75	338980.47	32133.05
441.02	127315.75	119574.97	9343.91	5.042	641926.00	602897.00	47111.99
442.16	106495.49	103111.70	6580.47	5.333	567940.50	549894.75	35093.65
443.04	97967.63	72601.33	12787.01	2.693	263826.84	195515.38	34435.42
443.38	106490.22	80510.52	36628.42	1.954	208081.89	157317.56	71571.94
443.78	72890.05	89588.50	7348.25	3.722	271296.75	333448.38	27350.19
444.79	95653.56	83939.54	11366.06	4.224	404040.66	354560.63	48010.23
445.38	99428.16	98477.27	13587.10	5.808	577478.75	571956.00	78913.88
446.99	106226.57	100607.74	7874.04	5.201	552484.44	523260.88	40952.88
447.35	130864.17	227008.98	5298.16	2.851	373093.75	647202.63	15105.05
448.07	112742.28	84925.23	18653.00	3.036	342285.56	257832.98	56630.51
448.50	112431.11	136815.64	12209.23	3.511	394745.63	480359.69	42866.61
449.40	75159.61	84421.70	2120.90	4.646	349191.53	392223.22	9853.70
TOTAL CROSS SECTION AVERAGES					5481828.00	5519490.50	591510.00
			FLOW CONDITIONS: SEPTEMBER UPGRADE				
439.94	45156.64	31166.26	13202.58	3.617	163331.58	112728.37	47753.73
440.25	129786.18	115835.02	10648.54	2.851	370020.41	330245.66	30358.99
441.02	128533.05	116154.98	9108.22	5.042	648063.63	585653.38	45923.64
442.16	107258.69	100575.17	6605.58	5.333	572010.63	536367.44	35227.56
443.04	96567.95	71089.05	12390.93	2.693	260057.50	191442.81	33368.77
443.38	108724.95	81219.57	33857.07	1.954	212448.56	158703.05	66156.72
443.78	74089.09	88129.27	7084.43	3.722	275759.59	328017.16	26368.25
444.79	95380.47	82069.42	10166.99	4.224	402887.09	346661.25	42945.37
445.38	99484.09	96169.41	12631.05	5.808	577803.63	558551.94	73361.14
446.99	106048.61	98538.23	7487.40	5.201	551558.81	512497.34	38941.97
447.35	133967.81	225878.19	5124.69	2.851	381942.25	643978.75	14610.49
448.07	111266.89	83631.32	16574.46	3.036	337806.28	253904.69	50320.06
448.50	112785.38	134799.67	11208.66	3.511	395989.47	473281.63	39353.61
449.40	74645.22	82751.45	2212.55	4.646	346801.69	384463.25	10279.51
TOTAL CROSS SECTION AVERAGES					5496481.00	5416497.00	554969.81

(CONTINUED)

TABLE E2 (CONCLUDED)

River Mile	Rainbow Trout WUA 1000 ft	Adult Brown Trout WUA 1000 ft	Juve-nile Brown Trout WUA 1000 ft	Reach Multi-Plier	Adult Rainbow Trout WUA C/S Total	Adult Brown Trout WUA C/S Total	Juve-nile Brown Trout WUA C/S Total
FLOW CONDITIONS: SEPTEMBER EXISTING							
427.80	56828.65	40021.48	5477.89	4.514	256524.52	180656.95	24727.20
428.64	35739.36	26021.46	6211.39	6.890	246244.19	179287.86	42796.48
430.41	58383.81	42475.82	11945.14	7.339	428478.78	311730.06	87665.38
431.42	64482.66	42283.78	18908.61	5.518	355815.31	233321.91	104337.71
432.50	90898.27	77910.36	9568.51	5.861	532754.81	456632.63	56081.04
433.64	68376.18	53527.46	5633.79	7.735	528889.75	414034.91	43577.37
435.43	101520.27	77853.93	8669.80	9.768	991650.00	760477.19	84686.60
437.34	107053.68	89298.59	7027.13	9.108	975044.88	813331.56	64003.10
438.88	93126.47	69431.98	21398.52	6.864	639220.06	476581.06	146879.44
TOTAL CROSS SECTION AVERAGES					4954622.50	3826054.00	654754.31
FLOW CONDITIONS: SEPTEMBER UPGRADE							
427.80	56421.43	39808.91	5891.65	4.514	254686.33	179697.42	26594.91
428.64	35118.04	25651.44	6195.01	6.890	241963.28	176738.42	42683.62
430.41	57822.40	42302.57	11926.02	7.339	424358.59	310458.56	87525.06
431.42	64762.44	42341.85	17781.15	5.518	357359.16	233642.34	98116.39
432.50	90805.30	76511.09	9294.79	5.861	532209.88	448431.53	54476.77
433.64	67638.62	52489.30	5721.31	7.735	523184.72	406004.75	44254.34
435.43	100636.82	76607.37	8370.81	9.768	983020.44	748300.75	81766.06
437.34	106779.14	87830.23	6752.60	9.108	972544.38	799957.69	61502.68
438.88	92599.37	68877.53	20744.82	6.864	635602.06	472775.38	142392.44
TOTAL CROSS SECTION AVERAGES					4924929.00	3776007.25	639312.31